USE OF LIFE CYCLE ASSESSMENT TO DETERMINE THE ENVIRONMENTAL IMPACT OF THERMOCHEMICAL CONVERSION ROUTES OF LIGNOCELLULOSIC BIOMASS: STATE OF THE ART

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Abstract:

The biomass is a promising way to substitute fossil fuels. Lignocellulosic biomass valorisation is part of second generation technologies. They are interesting in that they imply less competition with food crops for land and water, and they allow for the whole plant to be processed. Moreover, lignocellulose is abundant in cheap and non-food materials extracted from plants such as wood and energy crops.

In this work, the thermo-chemical route is being considered more extensively, especially the gasification process. This process converts carbonaceous biomass into combustible gases (CO, H2, CO2, CH4, and impurities) called syngas in the presence of a suitable oxidant. The syngas can be converted into a large range of products, such as diesel, via a Fischer-Tropsch process, or methanol, used for producing DME (dimethyl ether), both of which can serve as fuels in traditional motors. Syngas can also be used to produce ethylene and propylene, two building blocks for the chemical industry. Production of these four compounds is specifically investigated.

In order to insure that, under the principle of sustainability, the use of lignocellulosic biomass is a viable alternative, its environmental impact must be accurately quantified, using the Life Cycle Assessment (LCA) methodology. Within this context, this study focuses on the associated state-of-the-art. The gasification technology will be described, as well as existing LCA analysis of gasification processes. Finally, the need for new research and development regarding LCA of lignocellulosic biomass gasification and subsequent synthesis processes will be established.

Keywords: ACV- lignocellulosic biomass - thermochemical conversion

1. INTRODUCTION

The biomass is perceived as a promising way to substitute fossil fuels. Lignocellulosic biomass valorisation is part of second generation technologies. They are interesting compared to first generation technologies in the way they imply less competition with food crops for land and water, and they allow for the whole plant to be processed. Moreover, lignocellulose is abundant in cheap and non-food materials extracted from plants such as wood and energy crops (miscanthus, willow, etc.).

In this work, the thermo-chemical route is being considered more extensively, especially the gasification process. This process converts carbonaceous biomass into combustible gases (CO, H2, CO2, CH4, and impurities) called syngas in the presence of a suitable oxidant (air, oxygen or steam). The syngas can be converted into a large range of products, such as diesel, via a Fischer-Tropsch process, or methanol, used for producing DME (dimethyl ether), both of which can serve as fuels in traditional motors. Methanol can also be used to produce ethylene and propylene, two building blocks for the chemical industry. Production of these four compounds is specifically investigated (Figure ).
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2. THE CONVERSION PROCESSES

Biomass gasification is realized according successive steps (Figure 2) which include several processes and, for each process, various equipments are possible. The syngas use includes also several possibilities. So the entire chain for the lignocellulosic biomass valorisation is rather complex [1, 2].

Biomass pretreatment makes it suitable for gasification operations. Size reduction allows to obtain appropriate particle sizes: particles too small (less than 20 mm) will block the air supply when particles too large will lead to poor heat transfer because of smaller active surface and pores. Drying is needed to achieve moisture content smaller than 20 % so that the process can work efficiently. Some lignocellulosic biomass like miscanthus have moisture content lower than 20% when they are harvested in autumn so drying is not necessary. Densification may also be helpful due to the low density of biomass.

The gasification is obtained by heating between 600 and 1000°C the biomass with an oxidizing agent. The most important reactions are:

\[ C + \frac{1}{2} O_2 \rightarrow CO \]  
\[ C + O_2 \rightarrow CO_2 \]

Figure 1: Lignocellulosic biomass valorisation

Figure 2: Processes involved in biomass gasification
The gasification is a well-known process when the feedstock use is coke but when biomass is used some adaptations have to be made.

The oxidizing agent can be air, oxygen or steam. When oxygen is used, the syngas will have higher heating value because it gas is not diluted by nitrogen. When steam is used, the hydrogen content in the syngas is higher. Generally, the reactor is autothermal but sometime allothermal reactors are used and, in this case, the heat supply can be in direct or indirect mode. The oxidizing agent flow rate has also its importance: the higher the equivalence ratio (ER) or the temperature or biomass conversion, the smaller the syngas tar content, the residence time and the syngas LHV.

There exist several gasifier types presenting their own advantages and disadvantages. For example, the fixed-bed updraft gasifier is a simple and mature technology but the obtained syngas has a high tar content. Other possible reactor types are fixed-bed downdraft or multi-stage, fluidized-bed, etc.

The gas cleaning must be adapted to the gas use but generally, the following steps are necessary. The first step is the particles removal. These particles come from the biomass (ash and char) and the bed and can lead to plugging if they are not removed. A cyclone for the large particles can be used in combination with a wet scrubber. Barrier filters or electrostatic precipitators can also be used. After that, alkali removal can be done, for example, by cooling the gas and passing it through barriers filters. Generally, the nitrogen and sulfur compounds are in small amount, so their removal is not necessary. The tar elimination can be performed by primary (in the gasifier) or secondary methods. In this case, there are two possibilities: a wet scrubbing (water scrubbing followed by venturi scrubbing which allow to condense tar compounds) or a hot scrubbing (cracking the tar compounds at high temperature).

When the gas cleaning is finished, a water shift reaction can be used to obtain the best H₂/CO ratio depending on the application.

After that, chemical synthesis allows to obtain the desired product. Diesel can be obtained with a Fischer-Tropsch process. The reactions take place at temperature between 220 and 250°C with Co or Fe catalyst in a fluidized-bed reactor. The process is well established at an industrial level. The DME can be produced directly from the syngas. The reaction takes place at high temperature (240 °C) and high pressure (30 MPa) with a catalyst in a slurry reactor. But the DME can also be obtained from methanol. This one is produced from syngas in a fixed-bed reactor at temperature between 180 and 270°C, pressure between 50 and 100 bar using a Cu/Zn catalyst. After that the methanol is converted in DME using an alumina catalyst at temperature between 250 and 350°C. DME and diesel can be used as fuels. Finally, ethylene and propylene which can be used as building blocks for the chemical industry are also obtained from methanol with a combination of two processes: the methanol-to-olefin (MTO) process produces light and heavy olefins. The heavy olefins are converted to light olefins by cracking. Then, the Olefin cracking (OCP) takes place to convert the olefins into ethylene and propylene. Only the Fischer-Tropsch process is well known at an industrial scale. Nevertheless, there are pre-industrials or pilot plants for the other described process.

3. LIFE CYCLE ANALYSIS (LCA)

Once the processes have been well-understood, a review of the existing LCA has been done. No study about the environmental impact of the production of ethylene or propylene from lignocellulosic biomass with gasification could be found. Most of the studies compare the production of biofuels between them or with their fossil equivalent. When compared with fossil fuels, generally, biofuels perform better in view of global warming potential and emissions but are worst for the energy consumption [3-7]. When compared with 1st generation biofuel, the biofuel studied there obtain generally better environmental performance [8-10]. But all these studies have at least one of these lacks: only well-to-tank analysis and no well-to-wheel, few impacts categories, no economic point of view, no sensitivity check, no incertitude study. Moreover, only one study takes into account direct land use change and no one considers indirect land use change. Nevertheless, the impacts related to land use can be important [11]. So, new research is necessary in this emerging field of biomass valorization.

4. CONCLUSION

The gasification is a promising way for lignocellulosic biomass valorisation. But the processes are complex and numerous, so a well-understanding is necessary. Moreover, to assess any environmental gain, new LCAs have to been performed. Our future works aim to determine the better use of lignocellulosic biomass in the Belgium context based on extended LCA of this processes, using data

\[ \text{C} + \text{H}_2\text{O} \rightarrow \text{CO} + \text{H}_2 \]
coming from industrial partners or research laboratories leading large scale biomass gasification experiments.