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Lignin Valorization: Techno-Economic Analysis of Three Lignin Conversion Routes

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Abstract : Effective utilization of lignin is an important mean for developing economically profitable biorefineries. Current literature suggests that large amounts of lignin will become available in second generation biorefineries. New conversion technologies will, therefore, be needed to carry lignin transformation well beyond combustion to produce energy, but towards high-value products such as chemicals and transportation fuels. In recent years, significant progress on catalysis has been made to improve transformation of lignin, and new catalytic processes are emerging. In this work, a techno-economic assessment of two of these novel conversion routes and comparison with more established lignin pyrolysis route were made. The aim is to provide insights into the potential performance and potential hotspots in order to guide the experimental research and ease the commercialization by early identifying cost drivers, strengths, and challenges. The lignin conversion routes selected for detailed assessment were: (non-catalytic) lignin pyrolysis as the benchmark, direct hydrodeoxygenation (HDO) of lignin and hydrothermal lignin depolymerisation. Products generated were mixed oxygenated aromatic monomers (MOAMON), light organics, heavy organics, and char. For the technical assessment, a basis design followed by process modelling in Aspen was done using experimental yields. A design capacity of 200 kt/year lignin feed was chosen that is equivalent to a 1 Mt/y scale lignocellulosic biorefinery. The downstream equipment was modelled to achieve the separation of the product streams defined. For determining external utility requirement, heat integration was considered and when possible gasses were combusted to cover heating demand. The models made were used in generating necessary data on material and energy flows. Next, an economic assessment was carried out by estimating operating and capital costs. Return on investment (ROI) and payback period (PBP) were used as indicators. The results of the process modelling indicate that series of separation steps are required. The downstream processing was found especially demanding in the hydrothermal upgrading process due to the presence of significant amount of unconverted lignin (34%) and water. Also, external utility requirements were found to be high. Due to the complex separations, hydrothermal upgrading process showed the highest capital cost (50 M€ more than benchmark). Whereas operating costs were found the highest for the direct HDO process (20 M€/year more than benchmark) due to the use of hydrogen. Because of high yields to valuable heavy organics (32%) and MOAMON (24%), direct HDO process showed the highest ROI (12%) and the shortest PBP (5 years). This process is found feasible with a positive net present value. However, it is very sensitive to the prices used in the calculation. The assessments at this stage are associated with large uncertainties. Nevertheless, they are useful for comparing alternatives and identifying whether a certain process should be given further consideration. Among the three processes investigated here, the direct HDO process was seen to be the most promising.

Keywords : biorefinery, economic assessment, lignin conversion, process design
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