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Hydrogen from biomass: A detailed model to determine the potential of the sugarcane industry in Colombia

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Abstract

The hydrogen (H_2) market has an approximate value of 118 billion dollars with a 6.2% annual growth; however, some aspects like the cost of raw materials, high energy consumption, and its environmental trace generate serious concerns about its potential to mitigate the impacts on climate change. Compared to methane catalytic reforming (CH_4, 700 °C, 20 atm), synthesis of H_2 through the fermentative pathway presents a lower energy consumption as it is accomplished at an environmental temperature and pressure (35 °C, 1 atm). Production of H_2 by fermentative bacteria in the dark phase allows transforming simple sugars into a gaseous current (H_2 = 60% and CO_2 = 40%) and a liquid phase constituted by solvents and volatile fatty acids. The annual production of agricultural subproducts reaches 4.5 billion tons, these materials are essentially composed of cellulose (35%) and hemicellulose (25%). The latter suggests a potential production of up to 440 g (glucose) and 340 g (xylose) per each kilogram of generated waste. MethodologyThe best operational condition for the H_2-producing fermentative process was determined by means of a CCD (central composite design)-type factorial experimental design. The variables of interest were the concentration of the substrate (X1) and the concentration of microorganisms (X2), whereas de response variable was the yield of bioH_2 production (mol H_2 mol-1 substrate). Results: We obtained the following bioH_2 (mmol H_2 mmol-1 substrate) yields: 1.7 glucose ($C_6H_{12}O_6$) and 1.9 xylose ($C_5H_{10}O_5$). The latter corresponds to an efficiency of substrate utilization of 42.5% ($C_6H_{12}O_6$) and 57.6% ($C_5H_{10}O_5$). The operational pH (4.7) was a key element to warrant the high yield of the substrate because it allowed controlling the metabolic route, the hydrogenase activity, and the species present in the reaction medium (mainly Clostridium spp.). Yield and production velocity data for the bioH_2 enabled us to develop a stable state model in Aspen-Hysys V8.8 (Aspen Technology, Inc.), in which we estimated the production potential from cane bagasse (cellulose: 40%; hemicellulose: 30%; lignin: 20%; others: 10%). In the geographical zone of the Valle del Río Cauca (Colombia), 7 × 109 (ton/year) of bagasse are available; thus, it is viable to obtain 9.946 (ton BioH_2/year, 99.996% purity). The latter figure represents 0.014% of the worldwide consumption of H_2;

however, when compared to the catalytic reforming of natural gas there are notable aspects: 1) 29.3× 106 (m^3 CH_4/year) were not consumed and 100.000 (ton CO_2/year) were not emitted. 2) The use of an aerobic process coupled to the BioH_2 production process allowed recovering 156.800 (ton/year) of CH_4. 3) Catalytic reforming of the generated CH_4 will enable to additionally attain up to 31.360 (ton H2/year). Results suggest that it is feasible to obtain up to 41.360 (ton H_2/year) by using a renewable and abundant raw material like the cane bagasse.

Keywords: fermentation, hydrogen, reforming