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Production of bio-jet fuel from corncob by hydrothermal decomposition and catalytic hydrogenation: Lab analysis of process and techno-economics of a pilot-scale facility

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HIGHLIGHTS

- Process design and techno-economics of pilot bio-jet fuel facility were studied.
- Yields of furfural, LA, intermediate, bio-jet fuel were 59.5%, 34.4%, 75% and 51%.
- 47.6% energy and 31% carbon of carbohydrate in corncob is recovered in bio-jet fuel.
- TCP, OPEX and MSFB (no tax) was \$3.96 MM, \$1.18/L and \$1.45/L for a 1.3 ML/a facility.
- Economies of scale on MSFB is obvious when the discount rate increases and taxes impose.

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ABSTRACT

Process design and techno-economic analysis of a pilot bio-jet fuel production facility were investigated using Aspen plus software and net present value method (NPV). This process include two-step hydrothermal decomposition of corncob to furfural (steam stripping of hemicellulose) and Levulinic acid (LA, acidic hydrolysis of cellulose), oxygenated precursor production via aldol condensation reaction of furfural and LA, and the subsequent hydro-processing for oxygen removal. Lab experiments on the major area of the process were carried out. The yields of furfural, LA, oxygenated precursor and bio-jet fuel-range hydrocarbons (C_8–C_{15}) were 59.5% (based on hemicellulose), 34.4% (based on cellulose), 75% (based on furfural and LA input) and 51 wt% (based on precursor) respectively. These values were used as the input information for the process simulation of a first-of-a-kind pilot facility for 1.3 ML/a bio-jet fuel production using this pioneering technology.

The mass and energy analysis from Aspen plus model shows that the bio-jet fuel yield was 0.125 tonne/tonne dried corncob. 31.0% of carbon atoms and 47.6% of potential energy from carbohydrate compounds of corncob leave as bio-jet fuel. The estimated consumption of water, steam and electricity is relatively high of 12.3 kg, 63.7 kg and 1.22 KW h respectively due to small simulation scale and lack of process optimization. The total capital cost was ca. \$3.96 MM for the 1.3 ML/a facility, of which 28% of equipment investment is spent for oxygenated precursor production. The total operation expense (OPEX) is \$1.18/L bio-jet fuel, including variable and fixed costs. Expenses on corncob, catalytic catalyst and H_2 contribute 23%, 19% and 16% respectively. Single point sensitivity analysis of the major breakdown of OPEX shows that catalyst lifetime is the priority factor. Economy of scale of minimum selling price of bio-jet fuel (MSPB) for different capacity facilities (1.3 ML/a, 6.5 ML/a and 13 ML/a) was investigated using different discount and tax rates, of which the lowest MSPB was \$0.74/L with a subsidy of \$0.31/L at 10% discount rate.

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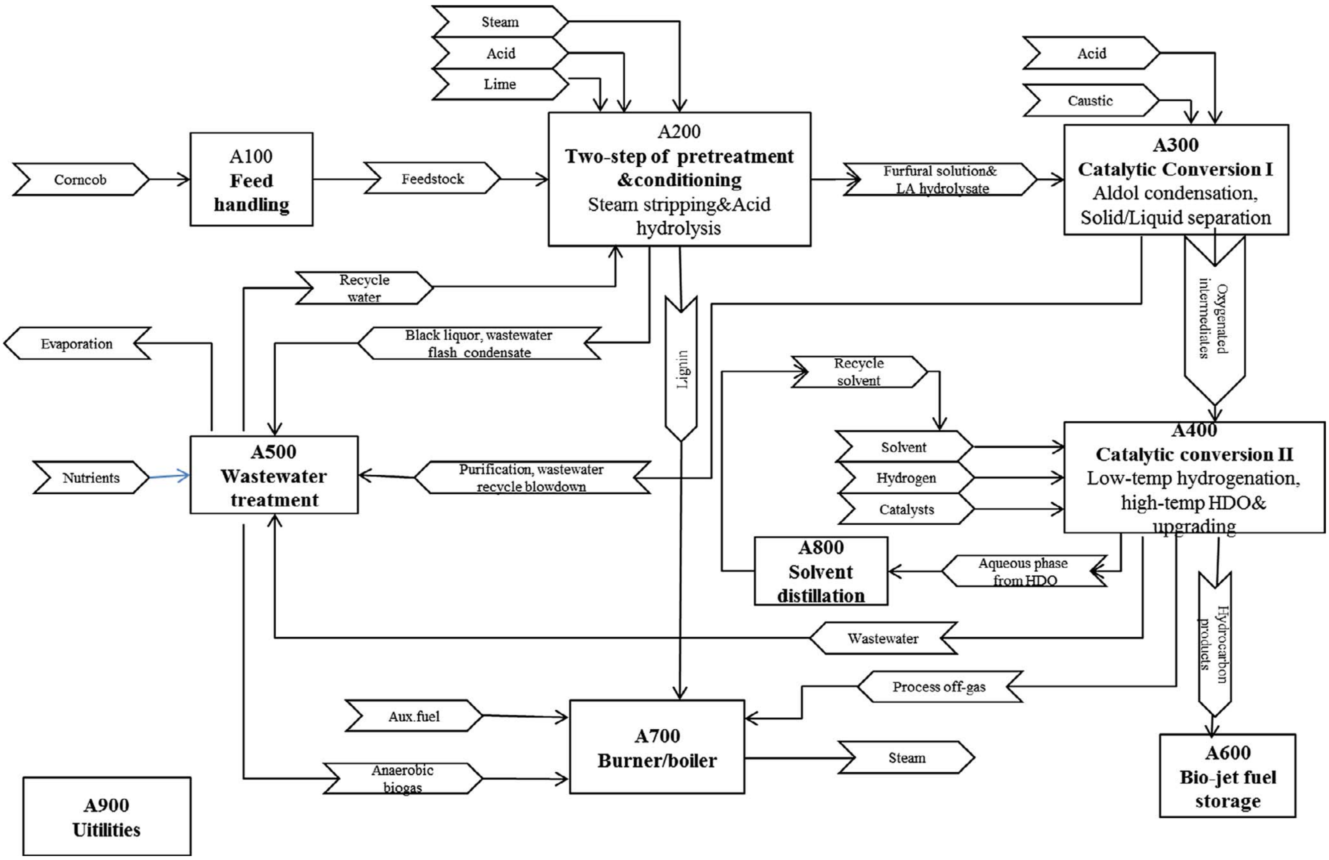

Fig. 1. Process diagram of bio-jet fuel production from corncob.

1. Introduction

Jet fuel consumption is approximately 1.5–1.7 billion barrels per year world-widely, of which accounts for ca. 9% of petroleum refining products [1]. With the increasing concerns of environment and energy issues, renewable bio-jet fuels from biomass are considered as potential alternatives to petroleum-derived jet fuel [2–4]. So far, hydrotreating esters and fatty acids process (HEFA) is a relatively mature technology for bio-jet fuel production commercially [4,5]. However, the limited availability of fatty/oil feedstock has restricted HEFA's development [6,7]. Industrial and academic attention is focusing on the substitute process using lignocellulosic biomass via thermo- or bio-chemical decomposition technology [8,9]. The produced intermediates such as syngas, alcohols, bio-oil and sugars would be converted to bio-jet fuels by further fermentative or catalytic process [10,11].

Recently special attention is on bio-jet fuel production in aqueous phase due to the mild hydrothermal condition for acidic or enzymatic hydrolysis of lignocellulosic biomass [12]. Various hydrolysis derivatives, such as furfural, 5-hydroxymethylfurfural (5-HMF), methyl furfural and levulinic acid (LA), and the corresponding catalytic conversion pathways have been intensively investigated [13–16]. Although bio-jet fuel production under hydrothermal condition is expected to improve process energy efficiency and its economy, few concrete results have been reported via techno-economic investigation, especially for pilot- or demo-scale facilities [17–19]. The integrated biofuel fuel process needs to optimize feedstock component, platform chemicals and conversion pathways to minimize cost and increase yield [20]. The efforts on exploring novel bio-jet fuel production process and evaluating first-of-a-kind facilities are still in urgent.

Using acetone, furfural and LA for aldol condensation reaction to obtain oxygenated precursors of bio-jet fuel with increased carbon-chain has been studied in our group [21,22]. The pioneering pilot facility with bio-jet fuel capacity of 0.13 ML/a was built in Liaoning Province, China. The test runs in this facility have been carried out to obtain useful information for process simulation.

The aim of this study is to perform a pilot-scale process design and simulation of this unique bio-jet fuel production technology that uses hemicellulose-derived furfural and cellulose-derived LA by two-step corncob decomposition, together with its techno-economic analysis. The novelty of this conversion pathway is that both cellulose and hemicellulose in corncob could be utilized, which increases remaining carbon in bio-jet fuel precursor via aldol condensation reaction between furfural and LA. This process includes the consecutive steps: two-step decomposition of corncob to furfural and LA, aldol condensation of these derivatives to oxygenated precursors of bio-jet fuel and the subsequent hydro-processing to produce jet fuel-range hydrocarbons (C_8–C_{15}). Techno-economic analysis agglomerates process information from the public domain and our lab experiment results, which was used for process simulation by Aspen Plus. Quantitative results of mass and energy were generated for economic analysis of a pioneering facility with production capacity of 1.3 ML/a bio-jet fuel. Economic analysis was to estimate both capital and operating expenses of bio-jet fuel (OPEX). Single-point cost sensitivity of major expenses on OPEX, such as feedstock price, catalyst lifetime and chemical used, was discussed. Economies of facility capacity scale of 1.3 ML/a, 6.5 ML/a and 13 ML/a, on minimum selling price of bio-jet fuel (MSPB), were also studied under different discount rate and incentive policy condition.

2. Methods

The process design and simulation was performed using ASPEN PLUS software to obtain material and energy balance data, which also assist in determining fixed capital investment (FCI), OPEX and MSPB. Corncob was used as feedstock and its composition was 39.2%