Nanocellulose production from lignocellulosic biomass in a Colombian context

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1. Introduction.

Lignocellulosic biomass is a complex biopolymer composed mainly of cellulose, hemicellulose, and lignin [1]. This type of biopolymer is the most available in nature [2] with annual production estimated to be around $1.3*10^{10}$ tons [3]. The lignocellulosic biomass utilization for the processing of novel composites has attracted growing interest because of their ecological and renewable characteristic [4]; one of which is the presence of cellulose in biomass that could be depolymerized into nano-dimensional biomaterial: Nanocellulose [1]. Different biomass was explored, as well as NC extraction and production processes. A key factor in determining the suitability of the feedstock for NC production is the relative abundance of cellulose as well as the pretreatment step of the lignocellulosic biomass [1].

In this work, the most commonly agro-industrial lignocellulosic biomass studied for obtaining NC were reviewed to define the raw material to be used in this study in the Colombian context and evaluate the economic feasibility. Different pretreatment methods for the isolation of cellulose and its subsequent treatment were compared. The operating conditions for the physical and chemical transformation of biomass were defined to establish a conceptual design of the biomass processing to obtain NC. NC production plant was designed in a process simulator to analyze the techno-economic viability to produce it from a lignocellulosic biomass. Some selection indicators were proposed to identify the best of the proposed designs, from operational and economic point of view. Finally, an evaluation of the logistics processes associated with the supply of raw materials was carried out.

2. Materials and methods.

The lignocellulosic biomass selection was carried out according two criteria: a) the availability of these wastes and b) the mass composition of cellulose, hemicellulose, and lignin of the waste reported in the literature. A selection of 3 pretreatments was made. The NC production plant was designed in the Aspen Plus v.10 process simulator. To make a description as close as possible to the real behavior of the process, it was necessary to define thermodynamic, kinetics, and separation aspects. The economic assessment of the process was carried out using the software Aspen Process Economic Analyzer v10. Among the cost analyzes generated by the simulator were the costs associated with equipment, utilities, and raw materials. The logistics analysis was carried out taking into account the aspects for the acquisition and transportation of the raw material for the best-simulated scenario.

3. Results and discussion.

According to the data reviewed, sugarcane bagasse (SCB) is the best candidate to produce NC due to the great availability in the sugarcane industry, its high cellulose content (53.2 %w/w), and low lignin content (32.2 %w/w). Asocaña [5] reports that 85% of the produced bagasse is used as an energy source in the same processes [6], but the energy efficiency of this process is lower than the one of other fuels for boilers, closed to 30 % [7]. Meanwhile the remaining 15% of SCB is used in the paper and agglomerate industry, composting and as livestock feed [5-6]. Considering the installed capacities of sugarcane bagasse production plants from lignocellulosic sources, described by Asocaña [5], annually in Colombia 6.5 million tons of sugarcane bagasse are produced. It was decided to start from a processing capacity of ∼15% of Colombian sugarcane bagasse production (1 million tons/year) in the designed plant, according to the percentage of sugarcane bagasse that is used in other processes than energy generation [6]. **Figure 1** shows the process flow diagram that was structured in Aspen Plus v.10. It is worth highlighting the PRETREAT hierarchy block, where a sub flowsheet diagram is incorporated, with the three pretreatments evaluated. This sub flowsheet is presented in **Figure 2Figure** . The steam explosion process (SE), Liquid hot water (LHW) and Organosolv method (OP) pretreatment methods are studied. The three pretreatments allow the removal of approximately 97% of the hemicellulose from the SCB plant sample. It is concluded that the OP pretreatment is the most suitable due to its efficiency on lignin and hemicellulose removal. Concerning the subsequent stages of alkaline hydrolysis, acid hydrolysis, and cellulose purification, the organosolv scenario has a higher cellulose recovery capacity than the other two scenarios (86.76% versus 74.62% and 75.62% of the vapor and liquid hot water explosion scenario, respectively). On the other hand, the OP scenario is the one in which more costs of raw materials, services, equipment, operating, and capital costs are incurred. Meanwhile, the SE scenario is the one that generates the highest annual dividends from product sales, and at the same time, the scenario in which incur fewer costs of raw materials, services, equipment, operating and capital costs.

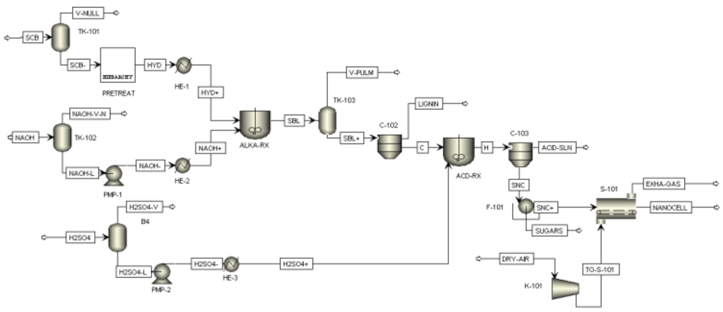


Figure 1. Main flowsheet design of NC production plant from SCB.

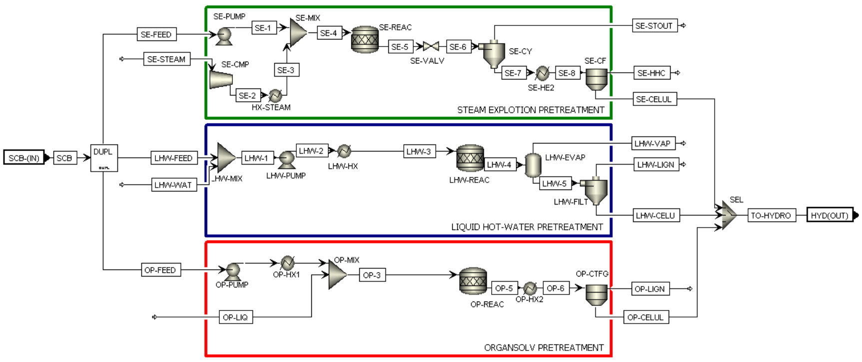
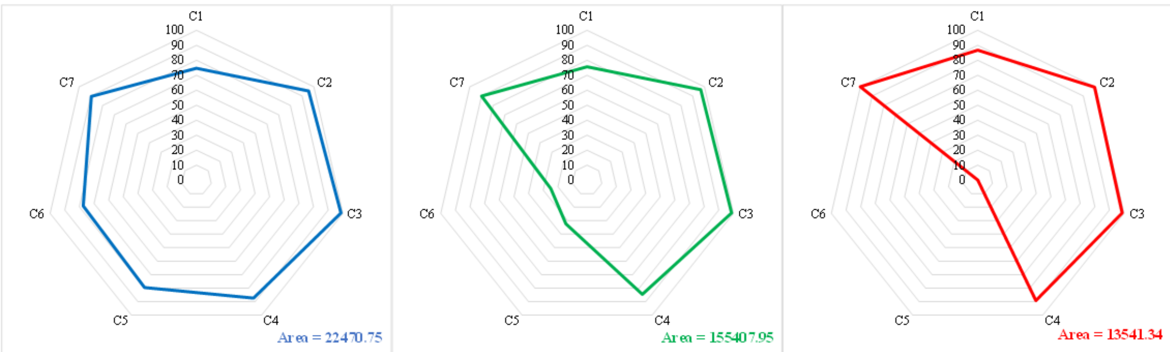


Figure 2. Sub flowsheet PRETREAT, used in the hierarchy block in the main flowsheet.

Finally, it was necessary to propose a multi-criteria consideration for the best scenario identification. Seven decision criteria were considered, represented on a scale between 0 and 100, where the higher value that the criteria takes, the better the results of that scenario in said criterion. **Figure 3** presents the results of the three scenarios where by integrating the area of the polygons obtained, it was determined that the best operating scenario is the SE scenario.



Convention: Scenarios: Blue = SE pretreatment, Green = LHW pretreatment, Red = OP pretreatment. Criteria: C1= Cellulose recovery (% w/w), C2 = Lignin removal (% w/w), C3 = Hemicellulose removal (% w/w), C4 = NC purity (% w/w), C5 = Total cost (USD/y), C6 = Production cost (USD/kg), C7 = NC produced (kg/h).

Figure 3. Multi-criteria consideration for each scenario.

4. Conclusions.

It was possible to develop the conceptual design of a processing plant of 1 million tons/year of sugarcane bagasse for the production of NC, based on related information in literature for the pretreatment of the lignocellulosic sample and the subsequent alkaline hydrolysis stage. and acidic. When carrying out the conceptual design, 3 scenarios of possible pretreatments were considered, to evaluate how the selection of the pretreatment affects the recovery of cellulose and the removal of hemicellulose and lignin at the end of the process. After carrying out the simulation and the economic evaluation of the three processes, it is concluded that the scenario with steam explosion pretreatment is superior from economic point of view.

On the other hand, the transportation of sugarcane bagasse is an important stage and its impact on production costs is of high importance, so any variation that is registered at this stage will have a great impact on the profitability of the product.

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