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Optimization of Lactic Acid polymer grade production at industrial scale

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Highlights

- Biomass lignocellulosic waste conversion into Lactic Acid with high purity level.
- Three different Lactic Acid production technologies have been analyzed and simulated.
- Process optimization and economic evaluation have been performed for these configurations.
- Lactic Acid polymer grade (99%) could be used for the Poly-Lactic Acid PLA production.

1. Introduction

This work is a collaboration between University of L'Aquila, Italy and APS's R&D department, recently created in order to research and develop new process technologies.

Nowadays Lactic Acid **(LA)** has different applications in the global market (food, pharmaceutics, cosmetics and chemicals) on the base of its purity. The most important application is Lactic Acid with high purity (99%) used to produce bioplastics, as it can be converted into the polymer Poly-Lactic Acid (**PLA**) through a series of reactions: polymerization, depolymerization and ring opening polymerization. This polymer is used in various fields, for example in the clothes industry, food and beverages, packaging, agriculture and others. Lactic Acid is commercially produced in two ways:

- chemical synthesis, using as source a fossil fuel;
- fermentation, where the feedstock is constituted by sugar and through a suitable microorganism it's possible to obtain Lactic Acid optically pure.

The LA optical purity is crucial for its physical properties. 90% of the whole LA production is obtained by fermentation, since it offers an alternative process preventing environmental pollution.

The scope of this work is to describe the tecno-economic feasibility and optimization of LA production process starting from pre-treated lignocellulosic biomass. In detail, three different process plant schemes have been studied and simulated with a process software simulator (ASPEN PLUS), using experimental data available in the literature. The three schemes differ mainly in the final purification section, meanwhile the production of LA by fermentation is similar in the examined cases. A technology produces LA with a purity of 88%, while the remaining two technologies lead to 99% LA purity. The fermentation step includes the enzymatic hydrolysis, where the feedstock is converted in sugars (C5-C6), which in turn ferment in presence of calcium hydroxide and produce calcium lactate. This stream is fed to an acidifier where Lactic Acid (low purity) is produced together with gypsum byproduct that is separated by precipitation. The downstream purification phase can be schematized as follows:
- multiple effect evaporation, (MEE), to reach 88% LA purity;
- MEE is followed by esterification with methanol, hydrolysis and product separation by means of a series of distillation columns to reach 99% LA purity;
- alternatively, the same purity level can be reached using a falling film evaporator, instead of MEE, and adjusting properly the esterification and distillation steps.

2. Methods

The activities relevant to this study can be grouped in 5 steps:

Step 1: Readout technical survey: Analysis of LA production technologies to identify those most promising to obtain high purity LA and suitable for process optimization by means of simulations on the plant scheme. On this respect, a critical aspect is represented by finding data of the reaction yields and the related operating conditions.

Step 2: Choice of the Process schemes: Based on the information provided by the literature sources, three process schemes have been developed in order to produce two different LA purities (88 and 99%). Starting from the same feedstock, three different Block Flow Diagram (BFD's) have been developed, considering products, byproducts and the operating conditions.

Step 3: Process simulations: After definition of unit operations, operating conditions and selected specifications, these data were implemented in the software Aspen Plus to carry out the process simulations of the plant schemes defined as previously described. Some unconventional components were initialized in the software through the NREL databank and some heat and stream recoveries were optimized under the required process specifications.

Step 4: Equipment design: After simulations were settled, the Process Flow Diagram (PFD's) was defined and major equipment items sized for each of the three options. Equipment choice has been carried out on the basis of well-established experience on the process plants. Equipment dimensioning was carried out through the help of engineering good practices and dedicated software as HTRI Exchanger Suite.

Step 5: Economic evaluations: The equipment sizing was used to evaluate the total cost for each of the three plant schemes, the results were obtained by means of dedicated equations and the calculation sheet CapCost, that includes Capex and Opex. The feedstock, chemicals and utilities cost was estimated too. On the base of the selling price of LA produced, the Payback Period was evaluated for each plant scheme. In order to obtain a direct comparison and to evaluate the best configuration.

3. Results and discussion

After an initial analysis about the compatibility with the process simulated in ASPEN, three thermodynamic models have been selected, one for each section of the plant schemes:

- Electrolyte NRTL, for the first section up to the separation of gypsum because of the presence of electrolitic species and ions in the reaction environment;
- NRTL for the second section about evaporation step for a non ideal mixture and polar components such as water and lactic acid;
- NRTL Hayden O'Connel for the last section about recovery and purification which provides accurate predictions for both phases in VLE.

The plant schemes studied in this work can be characterized as follows:

Plant A: LA purification with falling film evaporation and three distillation columns, with a production of 4736 kg/h. It can reach a final LA purity level of 99% and LA recovery level of 97%

Plant B: LA purification with MEE and four distillation columns, with a production of 4667 kg/h. It can reach a final LA purity level of 99% and LA recovery level of 96%

Plant C: LA purification with only a MEE, with a production of 5303 kg/h. It can reach a final LA purity level of 88 % and LA recovery level of 97 %.

The feedstock of the three plant schemes is lignocellulosic biomass with a mass flowrate of 7200 kg/h.

Other technical and economic results will be shown at the Conference.

4. Conclusions

Following the economic assessment of the three plant configurations, it has been found that all of them are economically feasible. The economic convenience of plant A and B is almost similar, although the former has a slightly more favorable economic return. So the choice between the two configurations should be assessed on the basis of additional factors, such as type and quantity of utilities available.

References

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Keywords

"lignocellulosic biomass", "polymer grade Lactic Acid", "process plant optimization", "tecno-economic evaluation".