MULTIPURPOSE FIXED-BED BIOREACTOR AND TRAY-TYPE BIOREACTOR IN THE PRODUCTION OF FERMENTED SOLID AND BIODIESEL: A COMPARATIVE ECONOMIC ANALYSIS

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ABSTRACT

The study conducted a preliminary economic analysis comparing two distinct industrial plants to produce fermented solid (FS) and biodiesel: one using a multipurpose fixed-bed bioreactor (Plant A) and the other a tray-type bioreactor (Plant B), both with an annual production capacity of 100 tons of FS and 1,000 tons of biodiesel. Utilizing SuperPro Designer® software version 8.5, process flow diagrams were designed for both plants, operating 24 hours a day for 333 days a year. The costs of equipment, supplies, and labor were obtained, resulting in a total estimated investment of USD 6,097,431 for Plant A and USD 5,553,004 for Plant B. The annual operational costs were USD 1,550,760 and USD 1,855,930, respectively. The minimum selling price was calculated at 1.90 USD/kg of biodiesel and 11.90 USD/kg of FS for Plant A, and 2.10 USD/kg of biodiesel and 14.10 USD/kg of FS for Plant B. Although Plant A had lower operational costs due to process intensification, the initial investment was higher due to innovation and the lack of industrial-scale data. The intensification of the bioprocess proved promising, with the potential to become competitive in the production of biocatalysts by reducing the minimum selling price by up to 15%.

Keywords: Fixed-bed bioreactor 1. One-pot system 2. Lipases 3. Esterification 4. Solid-state fermentation 5.

1 INTRODUCTION

With the increasing energy demand and concerns about global warming, biofuels emerge as promising alternatives, with biodiesel playing a leading role due to its biodegradability and low greenhouse gas emissions. However, traditional production methods have limitations, such as the production of alkaline wastewater and the high cost of enzymes used in biocatalysis. Solid-state fermentation (SSF) arises as a viable alternative, using agro-industrial by-products to produce fermented solid (FS) as biocatalysts. This approach not only reduces costs but also allows for more sustainable biodiesel production, integrating the oleaginous production chain and adding value to its residues. The economic analysis of this process is crucial to assess its economic viability, especially considering the need for more environmentally friendly and renewable energy solutions. The multipurpose fixed-bed bioreactor proposes an intensification of the production and application process of FS, aiming to reduce operational and investment costs, eliminating manipulation stages and final treatments of the biocatalyst.[1] Therefore, the objective of this work is to perform a preliminary comparative economic analysis between two types of bioreactors - the multipurpose fixed-bed bioreactor and the classic tray-type bioreactor - in the production of fermented solids and biodiesel. The economic viability of these systems were evaluated considering their operational and investment costs, and the efficiency of the FS and biodiesel production process.

2 MATERIAL & METHODS

The preliminary economic analysis was conducted through the design of two distinct plants (Multipurpose Fixed-Bed Bioreactor vs. Tray-Type Bioreactor), both with a productive capacity of 100 tons of SEP and 1,000 tons of Biodiesel per year, using SuperPro Designer® software version 8.5 (Intelligen, Inc.). The process flow diagrams (PFD) to produce Biodiesel and FS proposed for the two designed plants are demonstrated in Figures 1 and 2. The plants were designed to operate 24 hours a day and 333 days a year. The equipment costs were obtained from quotes with suppliers. The values obtained in real were converted to dollars considering the exchange rate of USD 5.20.

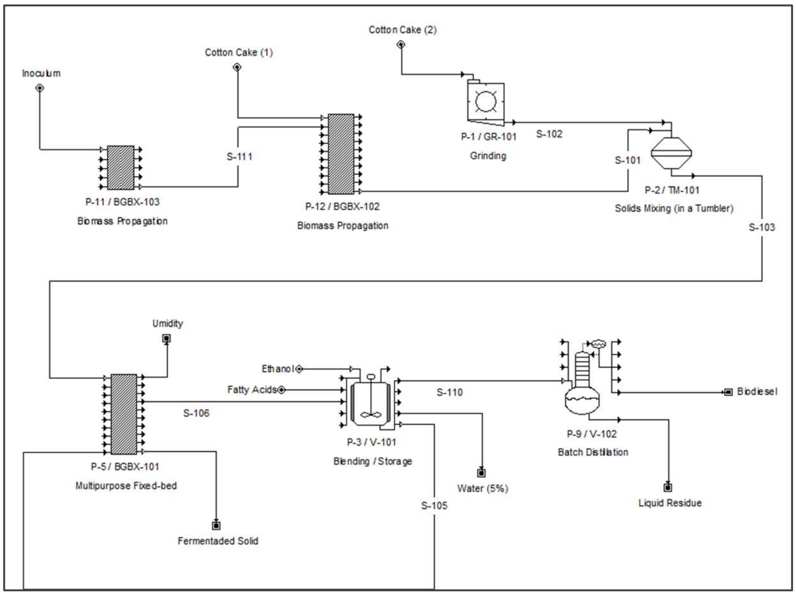

Figure 1. Plant A: Process flow diagram of biodiesel production in a plant utilizing a multipurpose fixed-bed bioreactor.

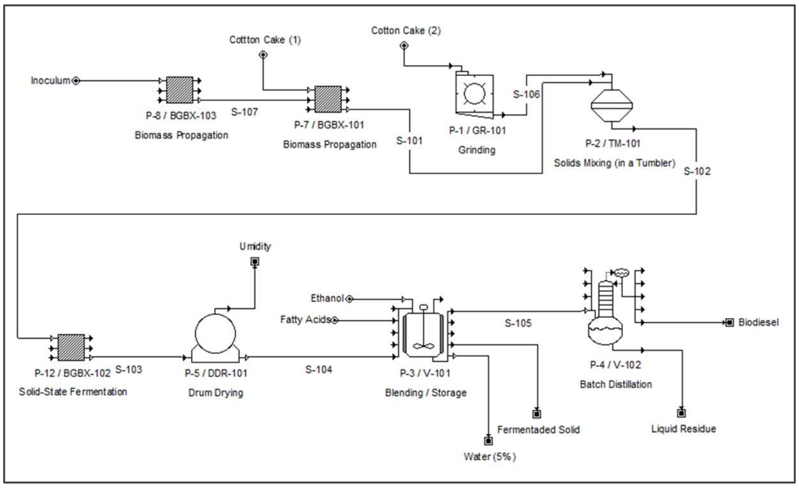

Figure 2. Plant B: Process flow diagram of biodiesel production in a plant utilizing a tray-type bioreactor.

The input costs were obtained from the Comex Stat database. The cost of cottonseed cake and distilled vegetable fatty acids were, respectively, USD 38.4615/ton and USD 10.6838/ton; these values were obtained directly from the suppliers. An industrial operator's wage was set at USD 5.24/hour. The demand for operators per equipment was estimated by multiplication factors.[2] The utility costs for process water, electricity, low-pressure steam, and cooling water were, respectively, USD 0.02/ton, USD 0.13/ton, USD 12.70/ton, and USD 10.00/ton. The Total Investment (CAPEX) was estimated by multiplication factors that mainly involve the cost of equipment. The Operational Cost (OPEX) was also evaluated, which mainly covers the direct costs of inputs, utilities, consumables, and labor.[2–4] Finally, the minimum selling price of FS and Biodiesel was estimated from the determination of the lowest positive net present value (NPV) with a 7% interest rate.

3 RESULTS & DISCUSSION

The total investment cost was estimated for both industrial plants in the production of 100 tons/year of FS and 1,000 tons/year of biodiesel, the details can be observed in Table 1. The total investment for biodiesel production in Plant A was USD 6,097,431, and USD 5,553,004 for Plant B. Plant A requires a higher investment by 9%, a need driven by the innovation of applying a fixed-bed bioreactor on an industrial scale and, in particular, the difficult scalability of fixed-bed bioreactors and the few references of bioreactors applied in industries.[5] Thus, the cost and size of the multipurpose fixed-bed bioreactor are conservative estimates, which negatively impacts investment costs.

The operational costs were calculated and are displayed in Table 2. Plant A requires operational costs of USD 1,550,760, and Plant B requires USD 1,855,930. Comparing the percentage operational cost of both plants, we can identify that the OPEX of Plant B is more impacted by labor costs, which was expected. Plant A reduces steps in the production of FS, decreasing manipulation and equipment use, thus reducing labor use (39% for Plant B and 22% for Plant A). With the use of by-products from the extraction and purification of oil (cottonseed cake and distilled fatty acids), the raw material impacts only 3% on the operational costs of biodiesel production using FS. This result demonstrates that, unlike alkaline heterogeneous biocatalysis, where raw materials impact more than 70% on production costs,[6] in our proposed process, raw materials have a low impact on operational costs.

Table 1 Detailing of the total investment cost comparison between the two plants for biodiesel production.

Description	Items	Cost Plant A (thousand USD)	Cost Plant B (thousand USD)
Listed Equipment (ISBL)	(1)	764	665
Unlisted Equipment (OSBL)	(2) = (1) x 0.30	229	200
Equipment Acquisition Cost	(3) = (1) + (2)	993	865
Fixed Investment	(4)	5,764	5,165
Start-up and Validation	(5) = (4) x 0.05	288	258
Working Capital	(6)	45	129
Total Investment (CAPEX)	(7) = (3) + … + (6)	6,097,431	5,553,004

Table 2 Comparative total operational costs between the two plants for biodiesel production.

Description	Items	Value Plant A	Value Plant B	Units
Inputs	(1)	114	114	thousand USD/year
Maintenance and Depreciation	(2)	1,056	969	thousand USD/year
Labor	(3)	337	713	thousand USD/year
Utilities	(4)	44	60	thousand USD/year
Total Annual Operational Cost of Biodiesel Production	(5) = (1) + … + (4)	1,550,760	1,855,930	thousand USD/year
Annual SEP Production	(6)	116	116	kg/year
Annual Biodiesel Production	(7)	1,146	1,146	kg/year

The minimum selling price was calculated considering a 7% interest rate, resulting in a value of 1.90 USD/kg of Biodiesel and 11.90 USD/kg of FS for Plant A, designed using a multipurpose fixed-bed bioreactor (Figure 1). For Plant B, which utilizes a tray-type bioreactor (Figure 2), a minimum selling price of 2.10 USD/kg of biodiesel and 14.10 USD/kg of FS was obtained.

4 CONCLUSION

The preliminary economic analysis indicated that the implementation of the multipurpose fixed-bed bioreactor reduces operational costs by intensifying the production of solid enzymatic preparations. However, there was no reduction in investment costs due to the lack of data and application on an industrial scale, leading to conservative estimates. Therefore, with the increase in the biocatalytic power of the enzymatic preparations and the reduction of production costs (up to 15%), the technology has the potential to become competitive with commercial biocatalysts. Furthermore, the technical analysis suggests that the technology can be applied in the biocatalysis of higher-value substances across various industrial sectors.

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