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Modelling and optimization of biodiesel production from jatropha oil: A comprehensive process simulation and economic analysis

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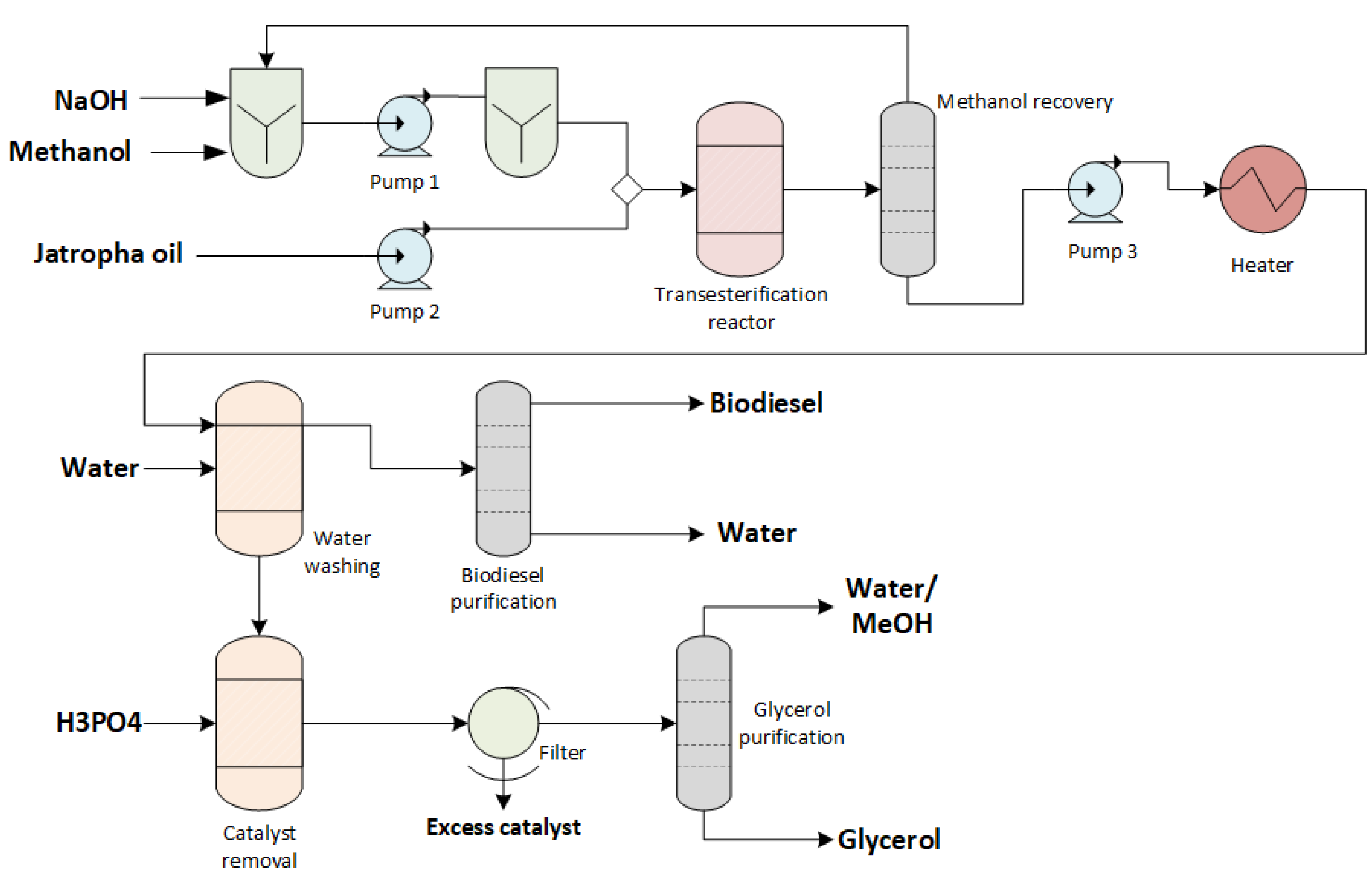
Introduction

- Rising energy demand and depletion of fossil fuel reserves highlight the need for sustainable alternatives
- Biodiesel is renewable, biodegradable, and reduces greenhouse gas emissions compared to conventional diesel.
- Jatropha curcas oil is a non-edible, high-oil-content feedstock that grows on marginal lands, avoiding food vs. fuel conflicts.
- **Research Gap:** Technical and economic challenges (such as process efficiency and cost competitiveness) limit large-scale biodiesel adoption.

Methods

The biodiesel production process was simulated using Aspen Plus® V11, incorporating key operations such as transesterification, catalyst removal, water washing, FAME purification, and glycerol recovery. The feed consisted of methanol and Jatropha oil, catalyzed by sodium hydroxide, under operating conditions of 60°C, 4 bar pressure, and a feed rate of 165 kg/hr. To optimize the process, Response Surface Methodology (RSM) was applied to identify the ideal parameters that maximize yield while reducing production costs.

For the economic analysis, Aspen Process Economic Analyzer (APEA) was employed to estimate both capital expenditure (CAPEX) and operating expenditure (OPEX). The Peter and Timmerhaus method was used to calculate Total Capital Investment (TCI), while a Discounted Cash Flow (DCF) analysis was performed to assess the profitability of the biodiesel production system.



Process flow diagram

Results & Discussions

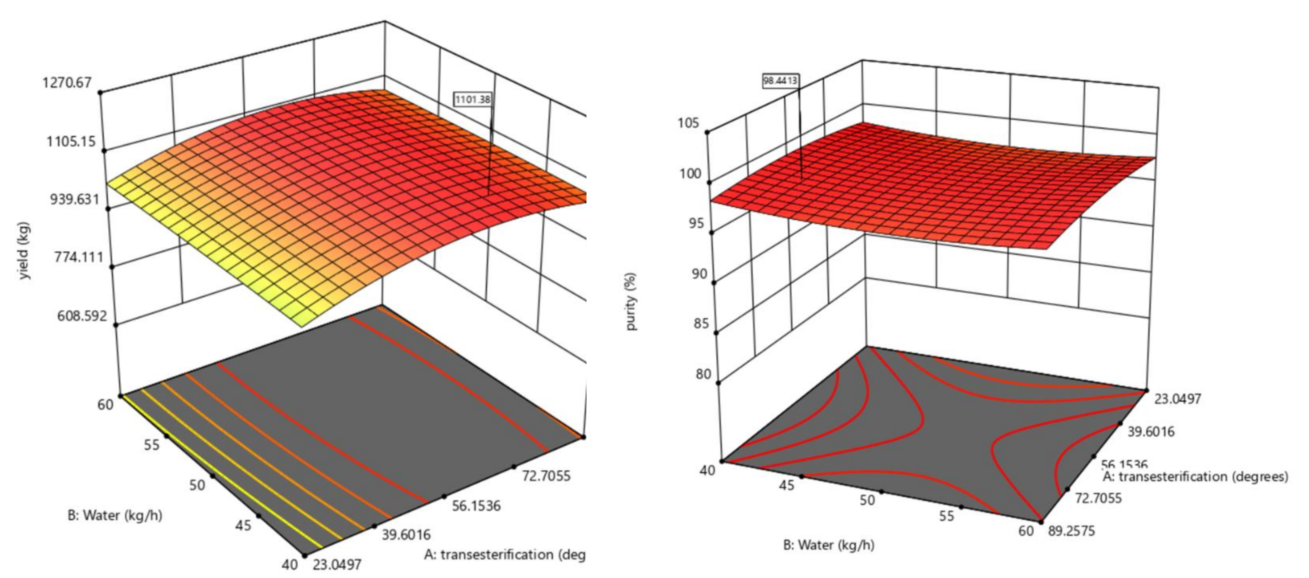
- **Biodiesel Yield:** The Aspen Plus simulation achieved an 83% biodiesel yield (FAME), calculated as the ratio of methyl ester mass flow (≈1016.27 kg/hr) to the total product stream (≈1223.06 kg/hr).
- **Glycerol Yield:** The process generated 9% glycerol yield, based on a glycerol mass flow of 110.62 kg/hr relative to the total stream flow.
- **Optimal Conditions for Maximum Yield:** The highest biodiesel yield was achieved at 63°C transesterification temperature, reflux ratio of 1.1, and 44 kg/hr water for washing. These conditions balance high conversion efficiency without excessive energy or operational costs.

Effects of Variables

✓ **Temperature:** Yield increases up to ~67°C, then declines due to methanol evaporation; too low temperatures reduce reaction kinetics.

✓ **Reflux Ratio:** Strong positive effect on yield and purity, but higher ratios increase energy and equipment costs.

✓ **Water Washing:** Minimal impact on yield, but improves biodiesel purity by removing impurities.



- **Cost and Profitability:** The minimum wholesale price of biodiesel was estimated at $0.62/L, with a retail price of $1.30/L, which is lower than conventional fossil diesel ($1.45/L). The project achieved a Net Present Value (NPV) of $58,99MM, indicating strong economic viability for a 20-year plant life.
- **Cost Drivers and Sensitivity:** Total Installed Equipment Cost accounted for the largest share of capital investment, while feedstock costs (~50%) and electricity (~40%) dominated operating expenses. Sensitivity analysis revealed that operating costs and jatropha oil feed have the greatest influence on the minimum fuel selling price, followed by biodiesel yield and methanol feed.

Conclusion

Biodiesel production from Jatropha curcas oil is technically feasible and economically viable, achieving 83% yield, optimized process conditions, and a competitive selling price of $0.62/L, making it a sustainable alternative to fossil diesel.