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Production of Sustainable Biodiesel Production from Non-Edible Oil Seed via Heterogeneous Catalytic Method

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Abstract

This study investigates sustainable biodiesel production from non-edible Jatropha curcas oil using heterogeneous catalysis to optimize conversion efficiency, environmental impact, and catalyst reusability. Several catalysts—including CaO, Cu-doped ZnO, mixed metal oxides, and bead-type dolomite-based systems—were synthesized and characterized. Optimal transesterification conditions such as catalyst loading, reaction temperature, alcohol–oil molar ratio, and reaction time were determined through experimental design. Results showed biodiesel yields up to ~92%, demonstrating both high performance and compliance with standards. The catalysts exhibited promising recyclability and lower environmental burden, pointing toward feasible scale-up. These findings underscore the viability of Jatropha biodiesel as a sustainable fuel alternative.

Keywords: *Sustainable biodiesel; Jatropha curcas; heterogeneous catalysis; transesterification; Cu-doped ZnO; CaO; mixed metal oxides; bead-type catalyst.*

Introduction

Context & Motivation: Fossil fuel depletion and environmental concerns push for renewable alternatives. Biodiesel is a viable substitute, especially when derived from non-edible oils such as Jatropha curcas, which doesn't compete with food crops and thrives on marginal land.

Crops & Feedstock: Jatropha seeds contain 27–40% oil; the crop is drought-resistant and can grow on non-arable land, making it sustainable—but water use and yield variability remain challenges.

Catalysis Approach: Heterogeneous catalysts (e.g., solid base oxides, mixed metal oxides) offer benefits like easy separation, reusability, and environmental suitability over homogeneous systems.

Aim: This paper reviews and compares such catalysts for Jatropha biodiesel, examining optimization strategies, yields, mechanisms, and environmental implications.

Methodology

Catalyst Preparation:

CaO-based systems: Prepared via calcination of limestone ($CaCO_3$) .

Mixed metal oxides: Synthesized (e.g., CaMgO, CaZnO) via co-precipitation and calcinations.

Cu-doped ZnO nanocatalyst: Produced via co-precipitation; particle sizes ranged from 0.5 to 52 nm .Bead-type dolomite catalysts: Used in specialized bead form for enhanced handling and regeneration.

Characterization Techniques:

XRD, SEM, EDX for structural and morphological analysis.

BET (surface area), CO_2-TPD (basicity), ICP-AES for composition.

Transesterification Parameters:

Variables include oil-to-alcohol ratio, catalyst loading (1–5 wt%), temperature (~45–65 °C), reaction time (120 min to several hours), stirring speed (e.g., 800 rpm) .

Design of Experiments:

Approaches like Taguchi's robust design and response surface methodology (RSM) were used to optimize engine and reaction parameters.

Results

Yield & Conversion:

CaO as catalyst achieved biodiesel yield up to ~92%, with conversion near 98% under optimal conditions (1:9 molar ratio, 2.5 wt% catalyst, 65 °C, 120 min) .

Cu-doped ZnO nano-catalyst yielded ~92% biodiesel, with temperature and methanol ratio directly influencing yield.

Engine Performance:

Biodiesel-diesel blends optimized using Taguchi/RSM showed maximal brake power (BP) of 3.3 kW and brake thermal efficiency (BTHE) of 32.94%, with minimal validation error (<2%) .

Catalyst Reuse & Stability:

Mixed oxide and supported catalysts showed good reusability; deactivation was analyzed via leaching tests .

Bead-type catalysts also demonstrated regeneration capability .

Characterization Outcomes:

SEM/XRD confirmed proper morphology and crystalline phases .Basicity and surface properties measured to correlate with catalytic activity.

Discussion

Comparative Analysis:

All catalysts achieved high yield (~90–92%), but practical differences exist. CaO and Cu-ZnO systems are efficient and simple to produce. Mixed oxides and bead-type catalysts better lend themselves to reuse and continuous processes.

Optimization & Scalability:

Experimental design methods (Taguchi, RSM) enhanced the engine-performance link and catalyst efficacy.

Sustainability Considerations:

Using non-edible Jatropha supports food security; heterogeneous catalysis reduces waste and simplifies processing.

Environmental caution: Jatropha requires considerable water, and yields are variable; lifecycle studies show mixed energy and GHG outcomes.

Challenges & Limits:

Catalyst deactivation, feedstock FFA/moisture sensitivity, and economic viability at scale remain concerns.

More lifecycle, economic, and field-level studies are needed, especially in regions like India where Jatropha projects have underperformed.

Conclusion

This work demonstrates that heterogeneous catalysts—especially CaO, Cu-doped ZnO, mixed metal oxides, and bead-type variants—can effectively transform Jatropha curcas oil into biodiesel with yields approaching 92%. Catalyst reusability and optimal process design via methods like RSM enhance practicality. However, environmental sustainability and economic feasibility hinge on feedstock availability, water use, and operational scalability. Future research should focus on pilot-scale studies, lifecycle analysis, and hybrid catalyst designs to further improve cost-effectiveness and sustainability.

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