Exploring Waste Cooking Oil in Biodiesel Production: A Review of Current Practices and Future Opportunities for Green Energy

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Abstract. Biodiesel produced from waste cooking oil has several environmental benefits, such as reduced greenhouse gas emissions, biodegradability, and improved engine lubricity relative to conventional fossil fuels. Furthermore, employing it for biodiesel mitigates waste disposal challenges, hence decreasing the pollution of terrestrial and aquatic resources. Notwithstanding these advantages, other problems persist, including composition fluctuation, contamination, and the necessity for effective purification and transesterification methods. The article examines many techniques for transforming waste cooking oil into biodiesel, emphasizing the critical phases of the transesterification process, which involve catalysts, alcohols, and reaction parameters. Furthermore, sophisticated methods like ultrasound-assisted and microwave-assisted transesterification are examined for their capacity to enhance efficiency and diminish processing duration. This research examines the sustainability dimensions of biodiesel production from it, highlighting its contribution to fostering a circular economy and minimizing waste. The utilization of its fosters a closed-loop system, whereby waste is converted into a valuable resource. Additionally, the evaluation examines the economic and social ramifications of biodiesel production, highlighting its capacity to provide employment, diminish import reliance, and bolster local communities. This analysis highlights the considerable potential of waste cooking oil for sustainable biodiesel generation. It necessitates ongoing study and technical advancement to refine processes, improve efficiency, and address current difficulties, therefore fostering a cleaner and more sustainable energy environment.

Keywords: Biodiesel. Waste Cooking Oil; Green Energy.

1 Introduction

Environmental alterations due to extensive fossil fuel use, combustion emissions, and resource depletion have generated interest in alternative fuel sources, such as biodiesel derived from waste vegetable oils and diverse plants, including Paratroop, castor, and sunflower [1]. The American Society for Testing and Materials characterises biodiesel as "mono alkyl esters of long-chain fatty acids obtained from vegetable oil or recycled cooking oil." Biodiesel is

ICIESC 2024, September 17, Medan, Indonesia
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DOI 10.4108/eai.17-9-2024.2352884

required to comply with a greenhouse gas emissions criteria, demonstrating emissions at least 50% lower than those of conventional fossil fuels [2]. Indonesia is significantly dependent on petroleum imports, satisfying just 30-40% of its local consumption and importing the remainder, which incurs an annual cost of around 1,000,000 million rupees. This need on imports might be mitigated by biodiesel production. The Intergovernmental Panel on Climate Change (IPCC) cautions that global temperatures must be constrained to 1.5°C to prevent catastrophic impacts on biodiversity, necessitating a 40% decrease in greenhouse gas emissions to achieve this objective. Biodiesel, produced from used cooking oil, has promise as a sustainable resource for fuel generation. It comprises free fatty acids that may be transformed into esters via a transesterification process including alcohol and an appropriate catalyst [3].

The burning of fossil fuels exacerbates climate change via greenhouse gas emissions, ocean acidification, and increasing sea levels, all of which adversely affect agriculture. Additionally, petroleum refineries are major contributors to air, water, and soil pollution, emitting contaminants like nitrogen oxides (NOx), carbon monoxide (CO), sulphur dioxide, and hydrogen sulphide. These emissions provide health hazards, leading to cancer, asthma, and reproductive complications. Additionally, refineries often use deep wells for wastewater disposal, which may result in the pollution of groundwater and surface water [8]. The increasing popularity of biodiesel is attributed to its environmental advantages over conventional fossil fuels. As it is derived from renewable sources such as plants and waste cooking oil, it provides a sustainable alternative that may diminish reliance on non-renewable resources and alleviate environmental problems. Biofuel production in the Netherlands, Indonesia, and the USA. The Netherlands prioritises advanced biofuels and sustainability, using bio-refineries that process rapeseed, maize and waste materials. Indonesia aims for energy independence by mainly manufacturing bioethanol from sugarcane and biodiesel from jatropha and waste cooking oil, with a goal of 20% ethanol blending by 2025. The United States, a worldwide leader, utilises maize for bioethanol and soybeans for biodiesel inside its Renewable Fuel Standard program.

Waste cooking oil (WCO) has become a significant resource for sustainable biodiesel production, addressing two major environmental issues: waste management and renewable energy generation [5]. Waste cooking oil, often disposed of in home and commercial kitchens, contains substantial quantities of free fatty acids that may be converted into biodiesel via the transesterification process. This transformation involves the chemical interaction of triglycerides in the oil with alcohol, usually methanol or ethanol, in the presence of a catalyst such sodium hydroxide or potassium hydroxide [6]. This method of repurposing WCO for biodiesel mitigates environmental damage and fosters a circular economy by converting trash into a useful resource. Biodiesel produced from waste cooking oil has several benefits compared to conventional fossil fuels, such as reduced greenhouse gas emissions, superior biodegradability, and increased engine lubricity. Moreover, its production bolsters local economies by generating new business prospects and diminishing reliance on imported fossil fuels. To guarantee the sustainability of biodiesel production from waste cooking oil, it is essential to tackle possible difficulties such feedstock fluctuation, contamination, and process efficiency. Current research seeks to enhance these procedures, augment production, and establish WCO as a dependable feedstock for biodiesel, thereby facilitating the worldwide shift towards more sustainable energy sources.

Biodiesel has several ecological benefits in comparison to conventional fossil fuels. Sources of biodiesel and its characteristics, including viscosity and pour point. It exhibits reduced pollution emissions, is biodegradable, and enhances engine lubricity, hence promoting sustainability [5,6]. A key attribute of biodiesel is its elevated cetane number, signifying superior fuel combustion quality. Biodiesel generally lacks aromatics and sulphur, with an oxygen level of 10-11% by weight, which results in reduced greenhouse gas emissions [7].

Waste cooking oil, originating from plant-based oils, serves as a substantial resource for biodiesel production. This oil is abundantly available globally, particularly in developing nations, yet improper disposal frequently results in environmental pollution. In the United States, approximately 100 million gallons of waste cooking oil are generated daily, with an average per capita production of about 9 pounds. In Canada, with a population of 33 million, the annual waste cooking oil output is estimated at 135,000 tonnes, while in European countries, it ranges from 700,000 to 1,000,000 tonnes per year. The elevated concentration of free fatty acids in waste cooking oil renders it a viable candidate for biodiesel production via the transesterification process.

Animal tallow serves as an additional source for biodiesel. In Brazil, it ranks as the second most used raw material for biodiesel manufacture, behind soy oil. Tallow has substantial amounts of saturated and unsaturated fatty acids, including 26% palmitic acid, 14% stearic acid, and 47% oleic acid.

Algae is a possible source for biodiesel owing to its elevated lipid content, with microalgae comprising 40-80% lipid by dry weight. This source needs little area and may be cultivated in either natural or artificial settings, using light, carbon dioxide, and nutrients for its development. Algae oil has 14.6% palmitic acid, 26.9% oleic acid, and 22.8% linoleic acid [8].

2 Research Method

Biodiesel, a sustainable substitute for traditional diesel fuel, may be derived from several feedstocks including vegetable oils, animal fats, and algae. Two main approaches for biodiesel extraction are mechanical and chemical procedures, each possessing distinct benefits and concerns.

The mechanical approach, referred to as the "transesterification" process, involves the extraction of biodiesel by a sequence of physical processes, devoid of chemical catalysts. This is a comprehensive outline of the stages involved:

a. Feedstock Preparation: The feedstock, including vegetable oil or animal fat, is first filtered to eliminate impurities or solid particulates.

b. Transesterification: The refined feedstock is then combined with an alcohol, often methanol or ethanol, in the presence of a catalyst. Prevalent catalysts include sodium hydroxide (NaOH) and potassium hydroxide (KOH).

c. Reaction: The mixture is swirled vigorously to promote the reaction between the alcohol and the triglycerides in the feedstock. This process produces biodiesel (methyl or ethyl esters) and glycerol.

d. Separation: Upon completion of the reaction, the mixture is let to settle, facilitating the separation of the denser glycerol from the less dense biodiesel.

e. Washing and Drying : The biodiesel is then rinsed with water to eliminate any residual contaminants or catalyst remnants. Ultimately, it is desiccated to eliminate surplus moisture.

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3 Results and Discussion

Vegetable oil undergoes viscosity alterations during the transesterification process. The removal of glycerol and other high-viscosity components results in the production of low-viscosity fuels. Following transesterification, the biodiesel's flash point decreases while its cetane number increases. Numerous factors influence the quality of biodiesel, including temperature, catalyst employed, reaction duration, moisture content, free fatty acid content, and the molar ratio of alcohol to oil.

The quality of biodiesel is mostly dependent upon temperature. As the temperature rises, the reaction rate increases, resulting in a reduction in reaction time and a decrease in the viscosity of the oil [12]. When the temperature exceeds the ideal range, the quality of biodiesel diminishes, resulting in the saponification of triglycerides and the vaporisation of ethanol. The reaction temperature is contingent upon the characteristics of the oils and fats used, with the ideal temperature ranging from 50 to 60°C.The temperature of the transesterification process must be below the boiling point of alcohol to prevent evaporation.

A faster reaction time leads to a more rapid conversion of fatty acid esters [13]. Due to the facile dispersion of alcohol and oil, the reaction will start slowly but then accelerate, concluding in around 90 minutes. Augmented reaction time will not lead to expedited conversion; rather, the reversible characteristic of transesterification—culminating in the depletion of esters and the formation of soap—will ultimately diminish the yield of biodiesel [14].

Given that esterification is a reversible process, the addition of additional alcohol to the mixture or the removal of excess product might enhance biodiesel yield. The reaction rate will reach its peak when all methanol is consumed. Due to its cost-effectiveness, polarity, and short carbon chain, methanol is often preferred over other alcohols like ethanol and propanol. Ethanol is favoured in the transesterification process because to its derivation from agricultural products, renewability, and less biological risk to the environment. The greatest achievable biodiesel yield is 99.5% at an oil to methanol ratio of 1:6 [15,16]. The production of biodiesel has risen in conjunction with the rising demand of methanol.

The kind and amount of catalyst applied will vary according on the specific type, alcohol concentration, and method utilised. Potassium hydroxide (KOH) and sodium hydroxide (NaOH) are the most often used catalysts in biodiesel production [17-18]. In the transesterification process, the inclusion of more catalyst often enhances ester yield; however, this approach is not economically viable due to the high cost of catalysts. Consequently, the production of biodiesel necessitates optimal utilisation of the catalyst [19].

Efficient mixing is essential in the transesterification process for ester synthesis, since alcohol and oil do not easily amalgamate, and reactions transpire at the interface of the two liquids [20]. Therefore, attaining optimum amalgamation of alcohols and oils is essential, with the necessary degree of mixing contingent upon the particular demands of the transesterification process. Vegetable oils, noted for their high viscosity, need intense mechanical mixing for complete integration; yet, modifications in the mixing intensity of input may provide uniform and acceptable outcomes. Studies indicate that, during the transesterification process, the reactants first create a biphasic liquid system [9,21]. The influence of mixing on the reaction rate is substantial at this stage; but, when phase separation ends, its effect wanes.

The availability of free fatty acids and water concentration considerably affects the transesterification of glycerides with alcohol when a catalyst is used. An excess of 1% w/w free fatty acid concentration results in soap formation, complicating the separation of glycerol and diminishing biodiesel output. The elevated water content in waste cooking oil exacerbates the hydrolysis process while concurrently reducing the production of esters [10-11]. Therefore, the supercritical methanol technique is used to mitigate this problem, since water has a negligible effect in this process. Maintaining a maximum moisture level of 0.5% is essential for attaining a 90% biodiesel production rate [22]. Surpassing the 0.5% threshold makes acid-based catalyst reactions more hazardous than base catalyst reactions, since alcohol interacts with free fatty acids, producing esters and water.

The use of waste cooking oil for sustainable biodiesel generation has excellent future possibilities, providing a dual answer to environmental and economic concerns. Technological improvements are enhancing conversion processes, hence improving the efficiency and cost-effectiveness of biodiesel production from waste cooking oil, facilitating scalable solutions. The amalgamation of biodiesel production with circular economy strategies would enhance sustainability activities, fostering a mutually beneficial connection between waste management and renewable energy generation. Furthermore, as governments globally emphasise environmental sustainability, the enforcement of biofuel blending laws may substantially enhance the market for biodiesel, encouraging the use of waste cooking oil as a useful feedstock.

Alongside technical developments, regulatory frameworks and quality standards will be essential in maintaining the integrity and sustainability of biodiesel derived from waste cooking oil. Stringent certification procedures will assure customers and stakeholders, enhancing trust in the environmental advantages and compatibility of biodiesel. Moreover, cooperation among governments, industry stakeholders, and research institutions will be crucial in fostering innovation, enabling infrastructure advancement, and encouraging extensive market acceptance. Through the integration of these collective initiatives and the enhancement of consumer knowledge, the prospects for using waste cooking oil in biodiesel production seem favourable, ready to advance significantly towards a more sustainable and environmentally friendly future.

4 Conclusion

Biodiesel is a viable alternative fuel, providing ecological advantages as a renewable and biodegradable choice for transportation. Biodiesel manufacturing offers varied solutions via a variety of feedstock alternatives, including animal fats, residual cooking oil, and algae. Transesterification, a commonly used procedure, depends on good catalysts, especially heterogeneous ones, to enable efficient conversion. Waste cooking oil functions as an economical feedstock, with acid catalyst treatment reducing its elevated fatty acid concentration. Although obstacles like water formation occur during esterification, sequential reaction pathways alleviate these problems. Methanol is favoured as an alcohol option because of its cost-effectiveness and simplicity of separation. In the future, choosing appropriate process technologies and eco-friendly catalysts will be essential for improving the economic feasibility and sustainability of biodiesel production. This highlights the persistent need for innovation and smart decision-making within the biodiesel sector.

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