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SHORT COMMUNICATION

Analysis of the use of waste cooking oil as an alternative fuel

Análisis del uso de aceite de cocina usado como combustible alternativo

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ABSTRACT

This paper analyzes the use of used cooking oil as a sustainable alternative for biodiesel production, highlighting its potential to reduce dependence on fossil fuels and mitigate environmental problems. Used cooking oil, abundant and inexpensive, offers a solution for waste management by aligning with the principles of the circular economy. Through methods such as transesterification, biodiesel derived from used cooking oil shows advantages such as biodegradability and lower greenhouse gas emissions, although it presents challenges such as high viscosity and nitrogen oxide emissions. The study reviews research that employs additives and advanced technologies to improve biodiesel properties and engine performance. Strategies such as blending with other fuels and incorporating nanoparticles have been shown to optimize thermal efficiency and reduce pollutant emissions. Despite its limitations, biodiesel from used cooking oil represents a technically and environmentally viable alternative, especially if support policies and improvements in its production are implemented. Used cooking oil is a promising feedstock for moving towards a sustainable energy transition, with significant benefits in waste management and reduction of the environmental footprint.

Keywords: Combustion Engine; Cooking Oil Biodiesel; Efficacy; Performance.

RESUMEN

En el presente trabajo se analiza el uso de aceite de cocina usado como una alternativa sostenible para la producción de biodiésel, destacando su potencial para reducir la dependencia de combustibles fósiles y mitigar problemas ambientales. El aceite de cocina usado, abundante y económico ofrece una solución para la gestión de residuos al alinearse con los principios de la economía circular. A través de métodos como la transesterificación, el biodiésel derivado este, muestra ventajas como la biodegradabilidad y menores emisiones de gases de efecto invernadero, aunque presenta desafíos como su alta viscosidad y emisiones de óxidos de nitrógeno. El estudio revisa investigaciones que emplean aditivos y tecnologías avanzadas para mejorar las propiedades del biodiésel y su rendimiento en motores. Estrategias como la mezcla con otros combustibles y la incorporación de nanopartículas han demostrado optimizar la eficiencia térmica y reducir emisiones contaminantes. A pesar de sus limitaciones, el biodiésel de aceite de cocina usado representa una alternativa técnica y ambientalmente viable, especialmente si se implementan políticas de apoyo y mejoras en su producción. El aceite de cocina usado una materia prima prometedora para avanzar hacia una transición energética sostenible, con beneficios significativos en la gestión de residuos y la reducción de la huella ambiental.

Palabras clave: Motor de Combustión; Biodiésel de Aceite de Cocina; Eficacia; Rendimiento.

INTRODUCTION

The global energy crisis and the growing pressure to mitigate the effects of climate change have led to a more significant focus on developing renewable and sustainable energy sources.[1] Fossil fuels, which currently dominate the global energy landscape, are associated with several environmental, economic, and social problems, such as the emission of greenhouse gases (GHG), the depletion of non-renewable natural resources, and the volatility of international prices. In this context, biofuels have emerged as a viable alternative to reduce dependence on fossil fuels and contribute to energy sustainability.[2,3]

Among the various raw materials used for the production of biofuels, cooking oil (UCO) represents an up-and-coming option. This by-product, generated in large volumes by households, restaurants, and food industries, is an easily accessible and low-cost waste.[4] However, its inadequate management has historically been a source of environmental problems, including water and soil pollution, and has contributed to unsustainable disposal practices. The conversion of used cooking oil into biofuels provides an effective way of reusing waste. It aligns this activity with the principles of the circular economy, maximizing the value of resources and reducing waste.[5,6,7]

Biodiesel from UCO is chemically similar to conventional diesel but has several key advantages. It is characterized by being biodegradable and renewable and having less impact on GHG emissions. In addition, the conversion process by transesterification is relatively simple and has been widely adopted in various contexts.[8,9,10,11] However, the use of biodiesel derived from UCO is not without challenges. Technical issues include higher viscosity than fossil diesel, which can affect engine performance, and a tendency to increase nitrogen oxide (NOx) emissions, a major air pollutant. Therefore, Research into improving biodiesel's physical and combustion properties remains an active area of study.[12]

Globally, interest in UCO as a feedstock for biofuels has grown considerably. Several studies have shown that modern technologies and innovative additives can optimize biodiesel performance and minimize emissions. Furthermore, blending UCO biodiesel with other fuels, such as fossil diesel, bioethanol, and even hydrogen, has proven to be an effective strategy for addressing technical challenges and improving combustion characteristics. These technological advances can potentially make UCO a fuel economically competitive, environmentally beneficial, and technically viable.[13,14,15]

This article aims to review the current state of Research on using cooking oil as a source of biofuels.

In a world where proper resource management and energy transition are more crucial than ever, cooking oil is an innovative and practical solution. This comprehensive analysis provides a solid foundation for future Research and industrial applications, highlighting the opportunities and challenges of implementing this technology to transform waste into valuable energy resources.

METHOD

The present review was conducted using a systematic search in the Scopus database, which was recognized for its broad scope and quality in peer-reviewed scientific publications. The search used the Boolean expression: combustion engine AND "cooking oil biodiesel" AND (efficacy OR effectiveness OR performance OR optimization) to identify articles related to biodiesel derived from used cooking oil in internal combustion engines. Inclusion criteria were defined to ensure the relevance of the selected studies. The articles had to have been published between 2019 and 2025, written in English and corresponded exclusively to the documentary typology of academic articles. Other publications, such as conference abstracts, brief reviews, and grey literature, were excluded.

The initial selection was based on a review of titles and abstracts to determine the relevance of the studies. Subsequently, a detailed reading of the full texts of the articles that met the inclusion criteria was carried out. The data extracted from the selected studies were organized into thematic categories. This organization made it possible to identify patterns, key results, and areas of opportunity in the field.

RESULTS AND DISCUSSION

Research into using UCO as a raw material for biodiesel production has gained increasing interest due to its potential to address issues of environmental sustainability, waste management, and dependence on fossil fuels. Although the results demonstrate the viability of UCO biodiesel, they also highlight specific challenges, especially related to thermal efficiency and nitrogen oxide (NOx) emissions.

Production methods and fuel properties

Conversion methods, such as transesterification and pyrolysis, play a crucial role in determining the properties and behavior of biodiesel. According to Gad et al., biodiesel produced by transesterification significantly reduces carbon monoxide (CO), hydrocarbon (HC), and smoke emissions compared to conventional diesel.[16] This is attributed to the high oxygen content of biodiesel, which improves combustion. However, this process also increases NOx emissions, which poses a significant challenge to its widespread adoption. On the other hand, although pyrolytic oils produce lower levels of NOx, they show less efficient combustion and higher

CO and HC emissions, limiting their applicability in internal combustion engines.[16,17]

Adding additives has proven to be an effective strategy for improving the properties of ACU biodiesel. Masera et al. evaluated the mixture of biodiesel with 2-butoxyethanol, which resulted in a 12,5 % reduction in fuel viscosity and a 3,7 % increase in thermal efficiency compared to fossil diesel18. This finding is significant, as the high viscosity of pure biodiesel often hinders its use in compression ignition engines. In addition, the incorporation of nanoparticles, such as cerium oxide (CeO2), has made it possible to improve combustion and reduce emissions significantly. Dinesha et al. reported that these nanoparticles reduced specific fuel consumption by 2,5 % and decreased NOx emissions by 15,7 % and smoke opacity by 34,7 %.[19]

Impact on performance and emissions

ACU biodiesel has proven to be effective in reducing polluting emissions compared to conventional diesel. Kaya et al. found that B20 blends (20 % ACU biodiesel and 80 % fossil diesel) achieved significant reductions in CO (29,27 %), HC (39,06 %) and smoke opacity (25 %) emissions.[20] However, NOx emissions increased slightly, suggesting that the oxidizing properties of biodiesel favor the formation of these compounds during combustion. Maksum et al. also emphasized that adjusting the fuel injection timing can help mitigate this NOx increase, especially in pure biodiesel blends.[21]

An important aspect is the impact of additives and combustion strategies on engine performance. Thomas et al. explored the use of ACU biodiesel in RCCI (Reactively Controlled Compression Ignition) engines with dual injection and exhaust gas recirculation (EGR) strategies.[22] These techniques achieved a 96 % reduction in NOx emissions and an 80 % reduction in smoke, demonstrating their effectiveness in optimizing performance and reducing pollutants. On the other hand, hydrogen induction in biodiesel mixtures also showed promising results. Thiagarajan et al. reported that combining biodiesel with hydrogen improved thermal efficiency by 3 % and reduced HC, CO, and smoke opacity emissions by 10 %.[23,24]

Technical and environmental feasibility

The research also highlights the importance of balancing energy efficiency and environmental sustainability. Although ACU's biodiesel shows a lower energy content than conventional diesel, its high oxygen content favors a more complete combustion and a reduction of HC and CO emissions. However, the challenges of NOx emissions and decreased thermal efficiency require innovative solutions. For example, the addition of additives such as carbon nanotubes or the optimization of engine operating conditions can mitigate these adverse effects.[25]

CONCLUSIONS

As a raw material for biodiesel production, UCO represents a sustainable and promising alternative to the growing energy demand and the environmental challenges associated with fossil fuels. The findings reviewed in this paper confirm that UCO biodiesel can significantly reduce polluting emissions, mainly carbon monoxide, unburned hydrocarbons, and smoke opacity, contributing to cleaner air and a smaller environmental footprint.

However, significant challenges requiring attention have been identified. These include nitrogen oxide emissions, which tend to increase due to the high oxygen content of biodiesel. This highlights the need to implement complementary strategies, such as exhaust gas recirculation, injection timing adjustment, and advanced additives, to mitigate this effect. Furthermore, the lower thermal efficiency of biodiesel compared to conventional diesel underlines the importance of further research into improvement methods, such as adding nano-additives or ternary mixtures with alcohols.

The integration of advanced technologies, such as nanotechnological additives and improved combustion strategies, has proven effective in optimizing the performance of ACU biodiesel. These advances compensate for biodiesel's intrinsic limitations, such as its lower energy density and higher viscosity, and enhance its environmental advantages, making it possible to use it in various applications, from conventional diesel engines to more sophisticated systems such as RCCI engines.

Practically, implementing ACU biodiesel must consider its availability and the costs associated with its production and improvement. The existing infrastructure for recycling and processing UCO must be strengthened to guarantee a constant and high-quality supply, particularly in regions with high waste oil generation. Likewise, government support and implementing incentive policies, such as subsidies for biodiesel production and regulations promoting its use, will be crucial for its large-scale adoption.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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