Chapter 6

A Comprehensive Review of Nano additives Applications for Enhancing Palm Biodiesel Performance in Internal Combustion Engine

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Abstract

Palm biodiesel is recognized as a promising alternative fuel for internal combustion engines (ICEs) due to its renewable origin, biodegradability, and potential to reduce greenhouse gas emissions. However, its lower energy density, higher viscosity, and limited oxidative stability restrict widespread utilization. The incorporation of nano additives into palm biodiesel has emerged as an effective strategy to enhance combustion characteristics, emission profiles, and engine efficiency. This review critically examines recent progress in nano additive applications for palm biodiesel, emphasizing their effects on fuel properties, engine performance, and emission behavior. In addition, it discusses prevailing challenges, assesses economic feasibility, and identifies future research directions for the sustainable deployment of nanoadditives in biodiesel-fueled ICEs.

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1. Introduction

The rising energy demand and environmental concerns have accelerated the search for alternative fuels. Biodiesel, particularly palm-based biodiesel, has been considered a potential substitute for fossil diesel due to its renewable nature. However, inherent limitations such as higher viscosity, lower calorific value, and increased NOx emissions necessitate performance-enhancing modifications. The application of nanoparticles in biodiesel has emerged as a viable solution to overcome these drawbacks by improving combustion efficiency and reducing emissions.

2. Literature Review

Numerous studies have explored the potential of nano additives to enhance the performance of biodiesel in internal combustion engines. This section provides an overview of relevant research findings on palm biodiesel and nano additive applications.

2.1. Palm Biodiesel as an Alternative Fuel

Several studies have demonstrated the feasibility of palm biodiesel as a substitute for conventional diesel fuel. According to Atabani et al. (2012), palm biodiesel exhibits comparable combustion characteristics to diesel but faces challenges such as higher viscosity and oxidative instability. Research by Ong et al. (2014) highlights the environmental benefits of palm biodiesel, including lower carbon emissions and biodegradability.

2.2. Role of Nano additives in Biodiesel Performance Enhancement

Nano additives have gained attention due to their ability to improve combustion efficiency, fuel atomization, and emission characteristics. Studies by Selvan et al. (2014) and Sharma et al. (2019) indicate that metal-based nano additives, such as aluminum and cerium oxide, act as combustion catalysts, reducing ignition delay and improving brake thermal efficiency.

2.3. Types of Nano additives and Their Effects

•Metal-Based Nano additives: Research by Sajith et al. (2010) and Baheta et al. (2018) demonstrates that aluminum and iron nanoparticles enhance combustion efficiency and reduce carbon emissions.

•Metal Oxide-Based Nanoadditives: Cerium oxide and titanium oxide nanoparticles have been reported to lower particulate matter emissions and enhance thermal stability (Jamshaid et al., 2020).

•Carbon-Based Nanoadditives: Studies by Patel et al. (2021) show that graphene oxide and carbon nanotubes improve fuel stability and oxidation properties, leading to better engine performance.

2.4. Impact on Engine Performance and Emissions

Several experimental studies have reported improvements in engine performance parameters, including brake thermal efficiency (BTE) and brake-specific fuel consumption (BSFC). Research by Karthikeyan et al. (2017) suggests that the use of cerium oxide nanoparticles in palm biodiesel leads to higher combustion efficiency and lower NOx emissions. Additionally, studies by Rajan et al. (2022) emphasize the reduction of CO and HC emissions with the addition of carbon nanotubes.

2.5. Challenges and Limitations

Despite the promising benefits, the use of nanoadditives in palm

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biodiesel presents challenges, such as high production costs, stability issues, and potential health hazards. Research by Yusaf et al. (2021) emphasizes the need for further investigations into long-term engine durability and environmental impacts.

3. Properties of Palm Biodiesel and Its Challenges in ICEs

Palm biodiesel is derived from palm oil via transesterification. It exhibits comparable cetane numbers to diesel but suffers from certain drawbacks, including:

- Higher viscosity and density
- Lower heating value
- Poor oxidation stability
- Increased NOx emissions
- Fuel injector clogging issues

These limitations affect engine performance, durability, and emissions. Nanoadditives have been explored as a solution to mitigate these issues.

4. Nanoadditives for Enhancing Palm Biodiesel Performance

Nanoadditives can be broadly categorized into metal-based, metal oxide-based, carbon-based, and hybrid nanomaterials. The primary function of these nanoparticles is to enhance combustion characteristics, reduce emissions, and improve fuel stability.

4.1. Metal-Based Nanoadditives

• Aluminum (Al) Nanoparticles: Enhance combustion by improving thermal conductivity and flame speed.

• Iron (Fe) Nanoparticles: Act as catalysts for complete combustion, reducing carbon emissions.

4.2. Metal Oxide-Based Nanoadditives

• Cerium Oxide (CeO2): Promotes oxygen availability for better combustion and reduces soot emissions.

• Titanium Oxide (TiO2): Enhances ignition properties and reduces particulate matter.

4.3. Carbon-Based Nanoadditives

• Graphene Oxide (GO): Enhances fuel stability and thermal conductivity.

• Carbon Nanotubes (CNTs): Improve cetane number and reduce CO and HC emissions.

5. Effects of Nanoadditives on Engine Performance

Several studies have reported improvements in engine performance due to the addition of nanoparticles to palm biodiesel, including:

•Brake Thermal Efficiency (BTE): Increased due to improved combustion characteristics.

•Brake Specific Fuel Consumption (BSFC): Reduced owing to enhanced fuel atomization.

•Combustion Characteristics: Reduced ignition delay, better flame propagation, and lower in-cylinder pressure fluctuations.

•Enhancement in Combustion Characteristics Nanoadditives improve the fuel-air mixture, leading to better atomization and higher combustion efficiency. Various nanoparticles, such as cerium oxide (CeO_2), aluminum oxide (Al_2O_3), and titanium dioxide (TiO_2), act as catalysts, promoting complete combustion and reducing unburnt hydrocarbons (HC) and carbon monoxide (CO) emissions.

•Reduction in Friction and Wear Nanoadditives in lubricants

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significantly reduce friction between engine components by forming a protective nanolayer. This reduces wear and tear, leading to prolonged engine life and improved mechanical efficiency. Common lubricant nanoadditives include graphene, molybdenum disulfide (MoS_2), and copper oxide (CuO).

•Fuel Economy Improvement the enhanced combustion characteristics and reduced friction contribute to lower fuel consumption. Studies have shown that the addition of nanoparticles can lead to fuel economy improvements ranging from 3% to 15%, depending on the type and concentration of nanoadditives used.

6. Emission Characteristics with Nanoadditive-Doped Palm Biodiesel

6.1 Reduction in Carbon Monoxide (CO) Emissions

Studies have shown that nanoadditives significantly reduce CO emissions by promoting better combustion. For example, titanium dioxide (TiO_2) nanoparticles, when added to palm biodiesel blends, act as an oxygen donor, leading to enhanced oxidation of CO into CO_2. Mujtaba et al. (2020) reported a 32.09% reduction in CO emissions in a TiO_2-doped palm–sesame biodiesel blend compared to conventional biodiesel.

6.2 Reduction in Hydrocarbon (HC) Emissions

Unburned hydrocarbons (HC) in biodiesel combustion arise due to incomplete oxidation. Metal oxide nanoparticles, such as cerium oxide (CeO_2), enhance combustion efficiency by improving the oxygenation process. Research by Venu et al. (2019) showed that palm biodiesel blended with cerium oxide nanoparticles exhibited up to a 25.4% decrease in HC emissions due to their catalytic oxidation properties.

6.3 Impact on Nitrogen Oxides (NO_x) Emissions

While biodiesel generally leads to higher NO_x emissions due to its oxygen-rich nature, nanoadditives can help mitigate this effect. Studies on graphene oxide and carbon nanotube-based nanoadditives have demonstrated that their thermal conductivity properties lead to improved atomization and lower peak combustion temperatures, reducing NO_x formation. However, some researchers found a slight increase in NO_x emissions due to the enhanced combustion characteristics, necessitating optimized dosage levels of nanoadditives.

6.4 Reduction in Particulate Matter (PM) and Smoke Emissions

Particulate matter emissions are significantly reduced in nanoadditive-enhanced palm biodiesel blends due to the catalytic activity of nanoparticles. Nanographene oxide has been found to lower smoke opacity levels by improving fuel atomization and complete combustion. Murugan et al. (2019) observed a notable decrease in smoke emissions with nanographene oxide-doped palm oil methyl ester blends, particularly at higher nanoparticle concentrations.

7. Synergistic Effects of Nanoadditives with Palm Biodiesel

The combination of different nanoadditives and other fuel enhancers, such as dimethyl carbonate (DMC), has been explored for improved emission control. Graphene oxide nanoplatelets, when used with DMC, were found to reduce brake-specific fuel consumption while simultaneously decreasing HC and CO emissions. A study on palm biodiesel with 10% DMC and 40 ppm graphene oxide nanoplatelets showed a 5.05% reduction in fuel consumption and a 25% decrease in HC emissions.

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8. Challenges and Future Prospects

Despite their benefits, nanoadditive applications in biodiesel face challenges such as high production costs, potential toxicity, and difficulties in homogeneous dispersion. Future research should focus on:

- Developing cost-effective synthesis methods.
- Investigating long-term engine durability impacts.
- Ensuring environmental safety and regulatory compliance.

9. Conclusion

The incorporation of nanoadditives in palm biodiesel presents a promising avenue for improving ICE performance, fuel economy, and emission reductions. However, further research is needed to optimize formulations, assess long-term effects, and establish economic feasibility for large-scale implementation. Future studies should also explore hybrid nanomaterials to maximize performance benefits.

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