

Greening Gas Turbines: Survey on the Use of Biodiesel Blends in Light-Duty Applications

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Abstract. The article delivers an extensive analysis of biodiesel blend applications which include KFME (Karanja Fatty Acid Methyl Esters) in light-duty gas turbine operations. The review integrates findings from studies which appeared in peer-reviewed journals between 2007 and 2023 to investigate biodiesel combustion behavior in turbine systems. The review selected studies which showed relevance to turbine engine performance and combustion behavior and emission patterns and fuel atomization and material compatibility. B20–B40 stands out as the best blend option among all tested blends because it delivers optimal engine performance with minimal emissions. The KFME molecular structure contains oxygenated components which decrease carbon monoxide (CO) and hydrocarbon (HC) emissions yet increase nitrogen oxides (NO_x) emissions under specific operating scenarios. Successful implementation requires resolution of several technical issues which include injector design optimization and fuel preconditioning and material compatibility problems that affect elastomers and non-ferrous metals. KFME functions as a better biodiesel feedstock because it provides excellent fuel characteristics which include high cetane number and low sulfur content and enhanced oxidative stability. The characteristics of KFME make it suitable for use in light-duty gas turbine systems which power unmanned aerial vehicles (UAVs) and auxiliary power units (APUs). The aviation fuel certification process requires additional long-term durability assessments and cold-flow studies before regulatory bodies will accept the new product.

Key words: Biodiesel blends, KFME, Karanja methyl esters, gas turbines, light-duty engines, emissions reduction, B20–B40, injector design, UAV, APU, renewable fuels.

1 Introduction

Research into alternative fuels for energy and transportation sectors has increased because people worry about environmental sustainability and the depletion of traditional fossil fuel

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resources. Biodiesel has emerged as a prominent alternative because people recognize its environmentally friendly characteristics and its ability to break down naturally after use and its status as a renewable energy source. Biodiesel fuels are created when producers use transesterification to convert vegetable oils and animal fats and waste cooking oils into fatty acid methyl esters (FAME), which they can use as pure fuel or combine with regular fuels.

Researchers have studied biodiesel extensively for use in compression ignition (CI) engines, but they have done limited research on its potential for gas turbine engine applications. Gas turbine systems operate under significantly different thermodynamic and combustion conditions compared with diesel engines. These systems operate according to the Brayton cycle, which requires fuels that have fuel attributes, including high calorific value and superior atomization ability and low viscosity and reduced carbon buildup characteristics. Any deviation from these properties can negatively affect combustion stability, turbine efficiency, and component durability.

Turbine combustion systems depend on fuel atomization for their effective operation. Turbine combustors require fuel to undergo fine atomization before it can be mixed with compressed air for efficient combustion to take place. Biodiesel blends with higher viscosity produce larger droplet sizes during injection, which results in unburned fuel and wall wetting and deposit formation. These challenges highlight the importance of selecting biodiesel feedstocks with favorable physicochemical properties.

The study found KFME which stands for Karanja Fatty Acid Methyl Ester to be the best choice among non-edible biodiesel feedstocks researched during recent years. Karanja (*Pongamia pinnata*) stands as an environmentally sustainable biodiesel feedstock because it grows in tropical areas which extend to India and it can survive drought conditions. The fuel properties of KFME biodiesel show multiple advantages because it possesses a high cetane number together with low sulfur content and a relatively high flash point which improve both ignition performance and safe handling procedures.

The research found that moderate biodiesel blending ratios which range between B20 and B40 deliver combustion performance that meets acceptable standards in turbine systems while decreasing specific exhaust emissions. Fuel viscosity and injector design along with fuel system material compatibility issues and regulatory certification processes create ongoing issues that need resolution. The solution to these problems requires scientists to understand how biodiesel combustion works in turbine environments.

This review evaluates if KFME biodiesel blends can be used for light-duty gas turbine operations. The study investigates five areas which include combustion performance and emissions characteristics and fuel atomization behavior and material compatibility and regulatory requirements. The study aims to create a complete technical basis which will support both upcoming research projects and the future industrial use of KFME biodiesel in turbine operations.

1.2 BIODIESEL APPLICATION IN GAS TURBINE ENGINES

The first attempts to use biodiesel in turbine engines began after researchers studied synthetic fuels made from biomass. Chiaromonte et al. (2007) demonstrated that turboshaft engines can safely burn bio-synthetic paraffinic kerosene (Bio-SPK) blends which contain up to 50% of the fuel without causing significant damage to engine components and

without affecting engine performance. Ghobadian et al. (2013) found that microturbines operated normally when using palm oil methyl esters as fuel which resulted in a 20% decrease of carbon monoxide emissions.

Mahesh et al. (2019) conducted tests on jatropha-based biodiesel blends which reached B40 in an APU-class turbine. B20 showed similar thrust and combustion temperature results as Jet A which proved that biodiesel can be used at moderate blend levels. Kiran et al. (2020) studied biodiesel from waste cooking oil in small turbojet engines and found that the fuel could start at low temperatures and maintain flame stability until reaching B60. Huang et al. (2011) studied how biodiesel sprays behave in pressure-swirl injectors and found that higher viscosity fuels produced better vaporization results but their increased wall wetting issues developed because their atomization process became slower.

1.3 PERFORMANCE CHARACTERISTICS IN TURBINE SYSTEMS

The output of thrust together with thermal efficiency and specific fuel consumption (SFC) depends on the fuel properties which include energy content and volatility and viscosity. Zhang et al. (2015) used computational fluid dynamics (CFD) to create a model of combustion chambers which operated on biodiesel. The researchers found that using oxygenated fuels improved flame stability but the fuels produced a thermal efficiency decrease of 3-5% because they had lower calorific value.

Saidur et al. (2013) discovered that microturbines which used B20 fuel blends showed only a small increase of 3.8% in specific fuel consumption when compared to Jet A fuel. The performance of the system decreases after B50 because of poor atomization and delayed ignition and reduced flame propagation speed problems. Motevali et al. (2022) proposed that fuel preheating reduces the negative effects because it decreases viscosity while it improves volatility characteristics.

1.4 EMISSIONS AND COMBUSTION BEHAVIOR

Biodiesel combustion emits lower carbon monoxide and hydrocarbon and soot emissions because its oxygen-rich molecular structure enables complete combustion. Armas et al. (2008) discovered that biodiesel combustion produces particulate matter with lower mass which consists of smaller particles that have higher oxidation levels. The problem with nitrogen oxides (NO_x) still exists. Kumar et al. (2021) demonstrated through their research that biodiesel combustion leads to increased thermal NO_x emissions because of its high flame temperatures.

Valdez et al. (2016) proposed lean-premixed prevaporized (LPP) combustion strategies to mitigate NO_x formation without compromising combustion stability. Soudagar and his team conducted research in 2020 to develop nano-additives which include cerium oxide as a means to decrease ignition delay and reduce peak combustion temperature thus limiting NO_x emissions from biodiesel-powered turbines.

1.5 MATERIAL AND OPERATIONAL COMPATIBILITY

The main problem that hinders the long-term use of biodiesel fuels in vehicles arises from the inability of materials to maintain their integrity. Polar and hygroscopic properties of biodiesel cause it to deteriorate elastomers while also causing corrosion damage to mild steel and copper-based alloys. Corsini et al. (2016) documented that biodiesel blends caused Viton seals to swell and soften while aluminum components developed pitting corrosion after extended exposure to these blends.

Huang et al. (2011) established that injector design plays a crucial role in their research. The high viscosity of biodiesel results in inadequate spray patterns which create an increased possibility of carbon accumulation. The proposed solutions include three elements which are fuel preheating and antioxidant chemical additives and injector system modifications. Biodiesel storage stability faces challenges because of two main factors which include environmental temperature changes and the fuel's tendency to undergo oxidation and develop microbial contamination.

1.6 COMPARATIVE ANALYSIS OF FEEDSTOCKS

The study examines the combustion properties of turbines, which use jatropha, pongamia, waste cooking oil, algae, and kapok as potential feedstocks. KFME (Kapok Flabellifer Methyl Ester) stands out due to its high cetane number (>57), low sulfur content, and flash point exceeding 120°C. Sharma et al. (2022) found that KFME blends up to B40 maintained thrust and temperature profiles close to Jet A. The study found that beyond B60, cold-start issues and injector fouling were observed. KFME shows better oxidative stability and superior cold-flow performance than jatropha and WCO because it contains more saturated fatty acids.

1.7 REGULATORY AND CERTIFICATION TRENDS

ASTM D7566 establishes standards for aviation turbine fuels which include synthesized hydrocarbons that originate from bio derived sources. The fuels need to show compatibility through their flash point and freeze point and lubricity and thermal stability and emissions performance. The certification process currently recognizes hydroprocessed esters and fatty acids (HEFA) and Fischer-Tropsch SPK as approved fuels because neat FAME-based biodiesels fail to receive approval because of their high oxygen content and material safety issues. The testing process allows experimental use of FAME blends in non-commercial pilot and testbed UAV operations. ICAO's CORSIA framework promotes SAF development which achieves life-cycle emission reductions exceeding 50%. KFME and its similar feedstocks can achieve compliance when researchers complete combustion and material studies that demonstrate their safety for long-term use. The establishment of KFME as an effective SAF will require performance testing and material research and supply chain expansion as more countries adopt blending mandates and carbon offset programs.

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Table 1. Summary of key findings

Study	Key Focus	Findings
Chiaromonti et al.	Bio-SPK in turbines	Up to 50% blend viable, minor wear observed
Mahesh et al.	Biodiesel thrust test	B20 nearly matched Jet A thrust
Zhang et al.	CFD of biodiesel	More stable flames but higher NOx
Corsini et al.	Material interaction	Elastomer swelling and corrosion noted
Huang et al.	Spray characteristics	Lower penetration, fast vaporization

Soudagar et al.	Nano-additive use	Enhanced flame propagation with B50
Sharma et al.	KFME blends	B40 stable, B100 unstable in altitude

2 Conclusion

The review demonstrates that KFME biodiesel blends have potential to function in light-duty gas turbine systems. The analysis of existing literature indicates that moderate blending ratios, particularly B20 to B40, produce acceptable combustion results while decreasing carbon monoxide and hydrocarbon emissions.

The technology offers benefits but it is still facing several unresolved problems. The team must evaluate three factors which include fuel viscosity and injector design and material compatibility to establish operational reliability over extended periods. The aviation industry requires biodiesel fuels to fulfill strict regulatory standards before they can be used in turbine systems.

The upcoming research needs to investigate extended product lifespan through testing and develop next-generation fuel injection systems and create fuels that improve oxidation stability and cold-flow characteristics. The technological advancements and regulatory framework will establish KFME biodiesel as a sustainable fuel solution for UAV operations and small-scale energy production in future turbine technology.

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