

## Investigation and Analysis of Use of Sunflower Oil and Karanj As A Bio Fuels In Gas Turbine

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### Abstract

Rising anxieties relating to environmental impacts of pollution, identified fossil fuel reserves, and fossil fuel combustibility have intensified interest in and to find more relevant alternative sources that are sustainable and renewable. So biofuels which is originated from vegetable oils are one of many possible renewable energy sources that may be considered alternatives to fossil fuels, especially where gas turbines are used. This review addresses sunflower oil as well as karanj oil as prospective biofuels for use in gas turbines. Sunflower oil, a widely available edible oil, has good combustion characteristics such as a high calorific value and relatively low viscosity following the transesterification process. Karanj oil, a non-edible oil, is widely available in tropical areas, therefore it will not disturb entire food chain, an issue with biodiesel production.

**Keywords:** Biofuels, Renewable energy, Alternative fuel, Sunflower oil, Karanj oil, Biodiesel

## 1. Introduction

### Background and Global Energy Scenario

The global demand for energy has witnessed a dramatic surge since last some decades, primarily driven by rapid industrialization, urban expansion, and population growth. Fossil fuels—comprising coal, petroleum, and natural gas—have long been the backbone of global energy systems. However, the over-reliance on these non-renewable sources has led to several critical challenges, including the degradation of fossil fuel reserves, rising fuel prices, and a drastically increase in greenhouse gas emissions. These emissions participates for global warming, climate change, and a host of environmental and health issues. As a result, there has been a global shift in focus toward renewable and sustainable sources of energy. From the various alternatives, biofuels—fuels derived from organic matter—have emerged as an important substitute for conventional fossil fuels. They offer the dual advantage of reducing dependence on fossil fuels and mitigating environmental impact. Biofuels can be produced from a wide range of feedstocks, including agricultural crops, animal fats, non-edible plant oils and waste cooking oil. (Kumar p. et all, 2017, Latha M et all, 2014)

### 2. Works of biofuels in gas turbine

Biofuels can be utilized for the combustion purpose in various thermal system, apart from that gas turbine is one of the system. In gas turbine, use of biofuels is also more efficient compare to internal combustion system and boilers due to heat losses as well as atomization properties Properties of biofuels is also more suitable for working in gas turbine. (Nayak C. Acharya et all, 2014) This can affect atomization, flame stability, thermal efficiency, and emissions profiles in gas turbine use. Consequently, extensive testing is needed to assess the use of a variety of biofuels in gas turbines, and to verify that they meet the expected performance and environmental compliance while not compromising engine functionality.

### 3. Vegetable Oils as Potential Biofuel Sources

Lots of researcher, academicians are taking interest for experimental work to use biofuels in thermal systems specially in our country because of availability of raw materials, crops and farming waste. Among the diverse sources of biofuels, vegetable oils are priorities due to their renewability, ease of production, and favourable combustion properties. Vegetable oils can be categorized into edible oils and non-edible oils. Edible oils have been focused more due to their cleaner profiles and wider availability in developed countries.

(Pandey A. et al, 2020) However, their use as fuel raises ethical concerns related to food security, especially in countries where hunger and malnutrition remain prevalent.

#### 4. Utilizing Sunflower Oil for Biofuel

Basically sunflower oil is made from seeds, majority of European and foreign countries used this oils for cooking, medicine and various processing units as a raw materials. For purpose as fuel it is produced by transesterification process. Compare to other oil it has some good favorable properties like low viscosity, stability during combustion and calorific values. From table 1.1, properties like viscosity, flash point, CV, cetan number and acid content, very much closer to neat fuel without compromising output and performance. Especially sulfur content is totally absent in sunflower oil so reaction during combustion is not create adverse effect in turbine. (Shah A et al, 2017) Additionally, large-scale use of sunflower oil as a biofuel raises concerns about competition with its food-related applications, which can affect its economic and environmental sustainability in the long run.

#### 5. *Pongamia pinnata* as a Sustainable Biofuel

Karanj oil, derived from the seeds of the *Pongamia pinnata* tree, represents a highly promising non-edible oil for biodiesel production. Native to the Indian subcontinent and Southeast Asia, Pongamia is a leguminous tree that thrives on marginal land and requires minimal water and maintenance. (Singh S.P et al, 2010) Its seeds contain 30–40% oil by weight, making it a viable candidate for large-scale biodiesel production. Compared to edible oils, karanj oil contains higher levels of free fatty acids (FFAs) and certain anti-nutritional compounds like karanjin and pongamol, which make it unsuitable for human consumption. (Verma P. et al, 2015) However, these properties do not hinder its suitability as a fuel source. With appropriate pretreatment and transesterification, karanj oil could become biofuels with good combustion properties. Studies show that karanj biodiesel has good ignition properties, appropriate viscosity, and lower emissions of carbon monoxide and particulates when compared to diesel.

This review has also indicated the challenges involved with using vegetables or vegetable oil based fuels such as increased viscosity, potential for carbon formation, and wear on engines over time. (Chaurasia S. et al, 2016) This concludes that sunflower and karanj oil-based biofuels present a viable alternative for partial or full substitution of fossil fuels in gas turbines, supporting cleaner energy production and contributing to a reduction in

greenhouse gas emissions. Further research into fuel blending, additive use, and combustion optimization is recommended to enhance their applicability and performance.

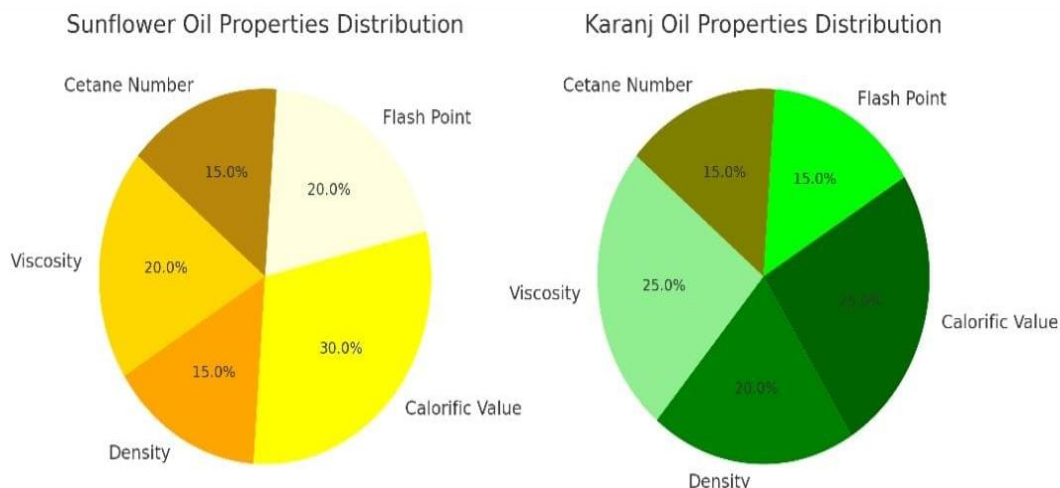
## 6. Relevance of Biofuels in Gas Turbine System

The feasibility of using biodiesel in gas turbines depends on several factors, including atomization characteristics, combustion stability, emission profiles, ignition delay, and overall thermal performance. (Zabeti M. et al, 2009) Biofuels tend to have higher viscosity and lower volatility than conventional fuels, which can affect spray formation and flame dynamics in gas turbines. Despite these differences, lots of practical are conducted with appropriate system modifications—such as optimizing fuel nozzles, preheating the fuel, or blending with conventional fuels—biofuels can be successfully utilized in gas turbine systems. (Rajak U. et al, 2020) However, increased NO<sub>x</sub> emissions have been reported, attributed to the higher oxygen content and combustion temperature of biofuels. Therefore, optimizing combustion conditions and adopting post-combustion treatment systems are essential to ensure environmental compliance.

## 7. Motivation for the Present Review

The dual pressures of energy insecurity and environmental degradation necessitate urgent action toward sustainable energy alternatives. In this context, both sunflower oil and karanj oil present viable solutions for partial or full replacement of conventional fuels in gas turbines. (Moser B.R.,2010) While individual studies provide work for the combustion behaviour of these oils, there remains a need for a consolidated review that compares and analyzes their performance, advantages, limitations, and suitability in gas turbine applications.

After referring data of karanj and sunflower oil from the past work, this review paper concluded feasibility of such oils for gas turbine. It shows that use of these oils with some percentage blending with diesel, gas turbine performance not too much affected. At lower load specific fuel consumption can be increase but can be accommodate at higher load.



**Figure: 1.1 “Comparative Properties of Sunflower Oil and Karanj Oil for Biofuel Applications”**

**Table 1: Comparison of Properties of Sunflower Oil and Karanj Oil for Biofuel Applications**

| Property                              | Sunflower Oil   | Karanj Oil (Pongamia pinnata)   | Diesel (Conventional) |
|---------------------------------------|-----------------|---------------------------------|-----------------------|
| Type                                  | Edible          | Non-edible                      | Fossil-based          |
| Oil Source                            | Sunflower seeds | Karanj seeds (Pongamia pinnata) | Crude petroleum       |
| Oil Yield (% by weight)               | 35–45%          | 30–40%                          | –                     |
| Density @ 15°C (kg/m <sup>3</sup> )   | 870–890         | 925–940                         | 830–850               |
| Viscosity @ 40°C (mm <sup>2</sup> /s) | 32–36           | 40–55                           | 2.5–4.5               |
| Flash Point (°C)                      | >220            | >200                            | 60–80                 |
| Calorific Value (MJ/kg)               | 39–41           | 37–39                           | 42–45                 |
| Cetane Number                         | 49–52           | 45–50                           | 47–55                 |
| Free Fatty Acid (FFA) Content         | <1%             | 5–20%                           | –                     |
| Sulfur Content (%)                    | Nil             | Negligible                      | Up to 0.5%            |
| Biodegradability                      | High            | High                            | Low                   |
| Toxicity                              | Non-toxic       | Contains karanjin,              | Toxic                 |

| Property                   | Sunflower Oil | Karanj Oil (Pongamia pinnata) | Diesel (Conventional) |
|----------------------------|---------------|-------------------------------|-----------------------|
|                            |               | pongamol (toxic)              |                       |
| <b>Oxidation Stability</b> | Moderate      | Good (with antioxidants)      | High                  |

## 8. Theoretical background

The use of biofuels in gas turbine systems requires a comprehensive understanding of various theoretical principles related to combustion, fuel chemistry, thermodynamics, and gas turbine engineering. As energy demands continue to increase globally, and environmental relation for fossil fuel combustion become more critical, the need to transition toward renewable fuels has become a top priority. (Srivastava A & Prasad R, 2020) Among the many renewable alternatives, biofuels derived from vegetable oils, such as sunflower oil and karanj oil, have shown significant potential. However, their effective use in gas turbines hinges on several critical theoretical considerations.

In gas turbine in ignition, the air-fuel mixture undergoes rapid combustion, producing high-temperature and high-pressure gases. (Ozcanli M & Sozen A., 2017) These gases expand through the turbine, generating mechanical work that drives the compressor and, in many cases, produces electrical or mechanical power. The efficiency and performance of a gas turbine are directly affected by the nature of the fuel used, especially its energy content, combustion behavior, and compatibility with the combustion system.

Combustion of fuels in gas turbines is a difficult because there is a chemical reactions between hydrocarbons and oxygen. For conventional hydrocarbon fuels, such as diesel or kerosene, combustion primarily involves hydrogen and carbon atoms reacting with oxygen and it produce carbon dioxide, water vapour and heat. The ideal stoichiometric combustion results in complete oxidation of fuel components. (Ramadhas et al, 2005) However, with biofuels—particularly those derived from vegetable oils—the molecular structure includes oxygen-containing compounds, leading to differences in combustion dynamics. The measuring of properties of biofuels is tough and very difficult. Biodiesel fuels are made up of long-chain fatty acid methyl esters, which possess inherent oxygen content that contributes to more complete combustion and potentially reduces emissions of carbon monoxide, hydrocarbons, and particulate matter . On the other side the imbibe of oxygen in the fuel

molecule and the higher combustion temperature can lead to increased formation of nitrogen oxides, one of the key pollutants in gas turbine exhaust.

First thing is calorific values, it's of diesel and bio-diesel is very much closer. So amount of fuel consumption is increase as compare to neat fuel. But this concern is important for large scale combustion system. Cetan number is concern with this phenomenon. (Zullaikah S. et al, 2013) Flash point, another important parameter for safe handling and storage, is significantly higher for biodiesel than for diesel, reducing fire hazards but sometimes requiring additional energy for ignition in cold-start conditions.

Thermodynamic and heat transfer principles also play an essential role in understanding how biofuels perform in gas turbines. The Brayton cycle efficiency depends on the pressure and temperature ratios achieved during operation. The introduction of biodiesel, which typically has a slightly lower energy content, could theoretically reduce the temperature of combustion gases and, consequently, the thermal efficiency of the turbine. (Salvi JP & Satturwar PM, 2017) However, due to the better oxygenation and combustion completeness of biodiesel, these effects can be mitigated or even reversed, especially in systems optimized for biofuel use. Additionally, the flame characteristics, heat release profiles, and pollutant formation can vary significantly depending on the chemical structure of the fuel. Biodiesel flames often burn cleaner but can produce different heat flux distributions, which affects the thermal stresses on turbine materials.

Due to more complete combustion, biodiesel generally results in lower emissions of CO, unburned hydrocarbons, and particulate matter. However, as previously mentioned, the elevated flame temperatures and oxygen content of biodiesel can lead to increased NO<sub>x</sub> emissions. The formation of thermal NO<sub>x</sub> in high-temperature regions of the combustor is explained by the Zeldovich mechanism, which shows that NO<sub>x</sub> formation increases exponentially with flame temperature. Strategies such as water or steam injection, fuel staging, and exhaust gas recirculation are commonly used in gas turbine systems to mitigate NO<sub>x</sub> emissions and can be applied effectively when using biofuels.

Another theoretical consideration is the material compatibility of biofuels with engine components. Biofuels have different solvency properties compared to diesel and may react with rubber seals, gaskets, and certain metals. Moreover, the presence of residual alcohol, moisture, or glycerin in poorly processed biodiesel can cause corrosion, deposit formation, or injector fouling. In high-speed, high-temperature environments such as gas turbines, these

issues can accelerate wear and reduce engine life. (Krishnan A et al, 2013) Therefore, high-quality fuel processing and periodic maintenance are essential when integrating biodiesel into turbine systems.

Blending biofuels with conventional fuels is another approach grounded in both theoretical and practical reasoning. By blending, say, 20% or 50% biodiesel with diesel (B20 or B50), it is possible to gain environmental benefits while minimizing the need for engine modifications. This also helps to balance the energy content and viscosity of the resulting fuel blend. Blending is particularly useful during transitional periods where infrastructure or regulatory systems are not fully aligned for 100% biodiesel usage.

## 9. Results and discussion

The application of biofuels such as sunflower oil and karanj oil in gas turbine systems has been extensively studied across various experimental and simulation-based research works. The findings from these studies explored useful information related to the feasibility, performance characteristics, and emission profiles of these alternative fuels compared to conventional fossil fuels. This section critically analyzes the results obtained in such studies, discussing key performance indicators such as thermal efficiency, specific fuel consumption, combustion behavior, and emissions. (Fjerback L et al, 2009) It also reflects on the influence of fuel properties, blending ratios, and engine modifications on overall gas turbine performance. Thermal performance includes factors like thermal efficiency and power output. Studies have consistently shown that thermal efficiency of both sunflower biodiesel and karanj biodiesel used in gas turbines tends to be about the same as that of petroleum diesel. However, in most trials there was found to be a minor reduction in peak power output. This is at least partly due to the lower calorific value of biodiesel which results in less energy being released for every kilogram of fuel used. To achieve the same energy production, more biofuel must be used, increasing specific fuel consumption. Despite the rise, there is not a significant variance in thermal efficiency amongst gas turbine engines, and any small variations can usually be eliminated or reduced by calibration and combustion parameter optimization. In gas turbine applications, biodiesel made from sunflower and karanj exhibits generally positive behaviour in terms of combustion performance. Biodiesels burn more thoroughly when intrinsic oxygen is present. But thicker viscous flow works properly by preheating them before introduce in combustion chamber. Addition to that atomization of this biofuel will also enhance. In comparison to heavy fuels or unrefined vegetable oils, the flame

is therefore steadier and has a shorter ignition delay. Experiments show that when sunflower biodiesels burn, the pressure rise tends to be smooth, suggesting sustained combustion with less oscillation. (Bhattacharya SC & Prakash R, 2004) As an oxygenated fuel, biodiesel can oxidize fuel molecules more thoroughly, resulting in lower percentages of partially oxidized molecules like CO and HC, which are caused by incomplete combustion.

## 10. Conclusion

The micro gas turbine engine's static thrust and thrust-specific fuel consumption decreased with biofuel blends, while thermal efficiency improved. When blending in further bio-diesel, one can expect that there will be a reduction in brake thermal efficiency at 5.2%, and a reduction in mechanical efficiency at 9.79%, with volumetric efficiency decreased by 2.59% reduction compared to neat diesel (Siraj Sayyed et al, 2022). All fuel blends when trialed resulted in higher static thrust, compared to neat Jet-A, with reduced fuel consumptions. R20E blend resulted in a 35% increase in static thrust and a reduction in fuel consumption by 41%, with thermal efficiency increasing by 24%. Moderate biofuel blending (e.g. B20) with Jet-A fuel exhibited similar performance characteristics to 100% Jet-A fuel while reducing most emissions, excluding Nox (Yazan SM et al, 2021). The overall performance of biofuel blends showed a reduced static thrust compared to Jet-A fuel while reducing CO and CO<sub>2</sub> emissions, there was no significant reduced in NO<sub>x</sub> emissions but it was beneficial at marginal decrease at engine rated speeds (Yuchen Liu et al, 2022). Coconut oil ethyl esters were blended with traditional Jet-A fuel were found to have increased density, viscosity, and freezing point, and decreased combustion heat. Engine performance tests indicated stable operations while exhibiting increased specific fuel consumption and a slightly longer start-up times with higher COEE concentrations. It was proven mixing COEE with traditional Jet fuel up to 30% was stable, but it increased fuel consumption (Anna Yakovlieva et al, 2025). Blending of recycled sunflower oil and mixed of sunflower oil and palm oil did not impair the performance and working of the turbo-engine (Grigore Cican et al, 2021). All in all, use of biofuels and its blends are providing tangible benefits for sustainable development.

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