Comparative Analysis of Performance and Exhaust Emissions from Jet A1 Blends with Various Aviation Biofuels

Dr. Sujesh G[1], Ms. Rinchu P[2], Mr. Prajeesh Raj V[3]

[1]Associate Professor, Department of Aeronautical Engineering, Jawaharlal College of Engineering and Technology, Palakkad, Kerala
[2,3]Assistant Professor, Department of Aeronautical Engineering, Jawaharlal College of Engineering and Technology, Palakkad, Kerala

Abstract
The aviation industry is a significant contributor to greenhouse gas emissions. Given the growing demand for air travel and the unsustainable use of fossil fuels, it is crucial to develop and commercialize renewable fuels to reduce these emissions. Conventional jet fuels like Jet A1 release harmful pollutants such as carbon monoxide (CO) and nitrogen oxides (NOx) into the atmosphere. In contrast, biofuels offer a renewable, biodegradable, and non-toxic alternative that emits fewer pollutants, excluding NOx, and is easier to treat than fossil fuels. Due to their eco-friendly characteristics, biofuels have garnered attention in recent years. This study focuses on producing biofuels from jatropha oil and waste cooking oil. Jatropha oil, aside from its medicinal benefits such as antimicrobial and anticancer properties, can be effectively used in industrial applications, particularly for biofuel production. The production of biofuels from jatropha and waste cooking oil is of growing interest due to their environmental and economic benefits. The study investigates the production of these biofuels using appropriate catalysts under controlled experimental conditions, followed by blending the biofuels with Jet A1 fuel to achieve similar engine performance while mitigating the environmental impact of greenhouse gases from petroleum-based fuels.

Keywords: Biofuel extraction, Biofuel, Jet A1, Jatropha oil, Waste cooking oil, Blending.

1. Introduction

Biofuel is a renewable energy source produced from biomass, including plant materials, algae, and animal waste. Unlike fossil fuels such as petroleum, coal, and natural gas, biofuels are derived from resources that can be quickly replenished, making them more sustainable. In the aviation industry, biofuels often referred to as bio-jet fuel or sustainable aviation fuel (SAF)—are seen as a critical tool for reducing the sector's carbon emissions. According to the International Air Transport Association (IATA), SAF plays a key role in achieving the industry's goal of carbon-neutral growth [1].

The environmental benefits of biofuels are significant, with studies showing that they can reduce carbon dioxide (CO_2) emissions by 20–98% compared to traditional jet fuel, depending on the type of feedstock used [2]. Biofuels can be produced from a range of raw materials, including crops, waste products, and algae, allowing for flexible sourcing. The first successful test flight with a biofuel blend was conducted in 2008, leading to the approval of up to 50% biofuel blends for commercial flights by 2011 [3]. Beyond reducing emissions, blending biofuels with conventional jet fuel improves various fuel characteristics, including lower freezing points, better viscosity, and enhanced combustion efficiency, thus contributing to overall fuel performance [4].

First-generation biofuels are produced from edible biomass, such as sugarcane and corn. Ethanol is obtained by fermenting C6 sugars using yeast strains like Saccharomyces cerevisiae [5], while biodiesel is made through transesterification, where plant oils are converted by replacing glycerol in fatty acids with methanol [6].

Second-generation biofuels come from non-edible lignocellulosic biomass, including wood chips, agricultural residues, and municipal solid waste. These biofuels align with the biorefinery concept, enabling the production of multiple products from a single feedstock [7]. Their conversion involves thermal or biological pathways, which are more complex than first-generation processes [8].

Third-generation biofuels are primarily derived from algae, known for high growth yields [9]. Microorganisms like Chlorella are used for their high lipid productivity. However, challenges include significant water requirements and complex dewatering processes before lipid extraction, which can be converted into biodiesel through transesterification [10].

2. Biodiesel Preparation

2.1 Waste Cooking Oil Methyl Ester (WME):

Waste cooking oil, typically sourced from food processing industries and households, contains impurities that must be filtered out before conversion into methyl esters. The conversion process largely depends on the free fatty acid (FFA) content of the oil, which is measured through titration. If the FFA level is below 4, the oil can proceed directly to transesterification. However, if the FFA content exceeds 4, an initial esterification step is necessary to lower the acidity before transesterification [11]

2.2 Jatropha Curcas Methyl Ester (JME):

The production of biodiesel from Jatropha oil involves a two-step process. Initially, esterification is performed to reduce the FFA content, which involves heating the oil and mixing it with methanol and sulfuric acid. This is followed by transesterification using sodium hydroxide and methanol to convert the oil into biodiesel. The resulting biodiesel is then separated, washed, and dried to remove any residual impurities, ensuring a clean final product [12].

2.3 Jet A1

Jet A1 aviation fuel is a high-performance kerosene-based fuel primarily used in commercial aviation and turbine-engine aircraft. It is characterized by its low freezing point and high energy density, making it suitable for high-altitude flight operations. Jet A1 is refined from crude oil and undergoes rigorous quality control measures to meet international standards, ensuring its compatibility with various aircraft engines. The fuel's chemical composition primarily consists of hydrocarbons, and it is designed to provide optimal combustion efficiency, which translates into reduced emissions and improved engine performance [13]. Additionally, the aviation industry is increasingly exploring the incorporation of sustainable aviation fuels (SAF) to mitigate the environmental impact of conventional Jet A1. SAFs, produced from renewable resources, can blend seamlessly with Jet A1, offering a promising pathway for reducing greenhouse gas emissions without compromising aircraft performance [14].

3. Blending of Biodiesel with Jet A1

Blending involves mixing biofuels with Jet A1 fuel to enhance its overall characteristics. In this study, biofuels derived from Jatropha oil and waste cooking oil were combined with Jet A1 in ratios of 70:30 and 80:20. The primary objective of this blending process is to harness the beneficial properties of both fuel types while mitigating the adverse effects associated with conventional petroleum-based fuels, particularly in terms of greenhouse gas emissions.

The blending was performed at controlled temperatures to maintain fuel stability and ensure homogeneity. Finally, the blended fuel underwent rigorous testing to evaluate its physical and chemical properties, including viscosity, density, and Calorific value, etc to ensure compatibility with aviation standards.

4. Characterization of Fuel Blends

In comparison, JME-Jet A1 blends tend to have better fuel properties, with lower density and viscosity, and higher calorific values, which make them more energy-efficient and easier to handle in engines. However, WME/Jet A1 blends exhibit higher flash and fire points, making them safer in terms of combustion risks. Both biofuel types show promise in reducing environmental impacts when blended with Jet A1, with each blend offering specific advantages in fuel performance.

Table 1: Physical Properties of blends

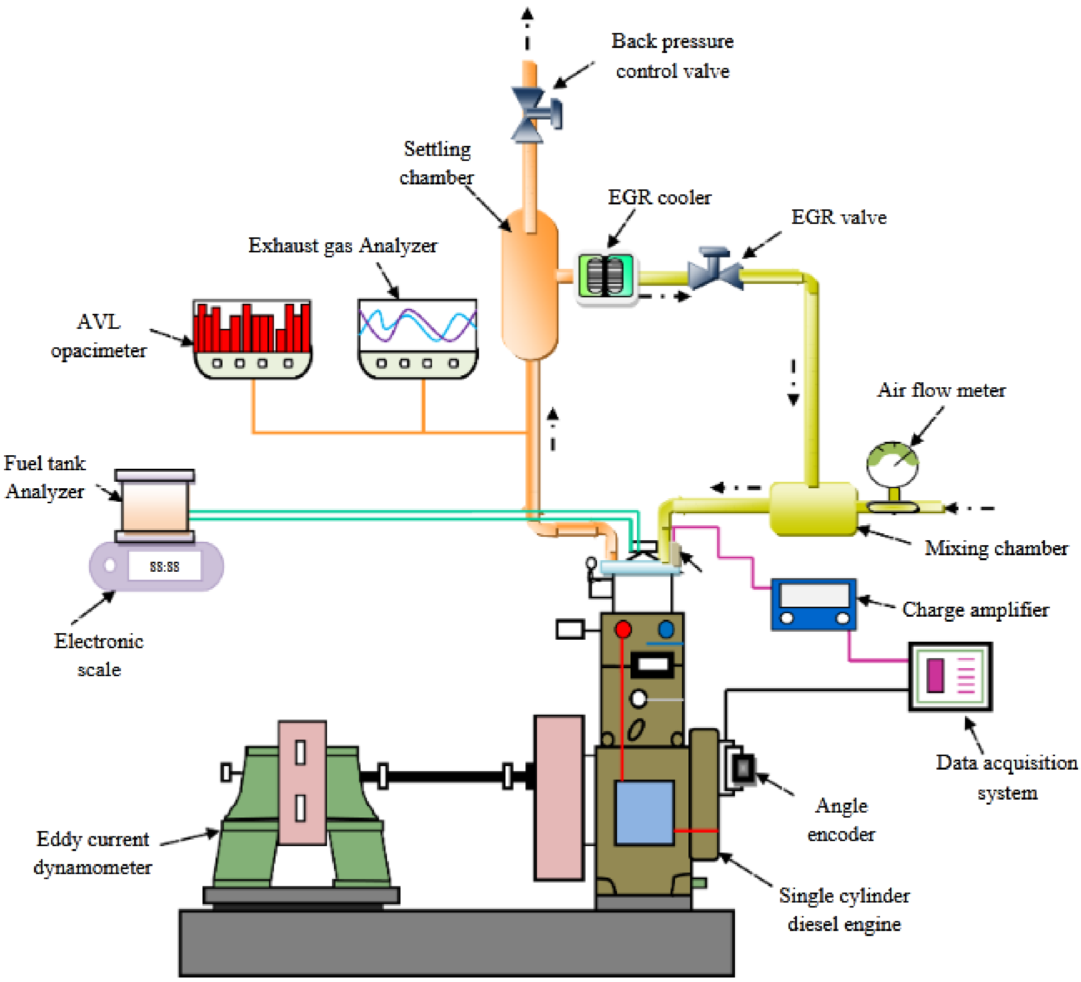
PARAMETERS	Jet A1	70:30 of WME/Jet A1	70:30 of JME/Jet A1	80:20 of WME/Jet A1	80:20 of JME/ Jet A1
Density (g\cc)	0.780	0.825	0.811	0.804	0.803
Kinematic viscosity (cSt)	1.2	0.504	0.434	0.406	0.364
Flash point (^{0}C)	38	85	72	78	72
Fire point (^{0}C)	56	92	80	86	80
Calorific value (MJ/Kg)	43.5	37.94	41.91	40.88	42.37

In comparison, JME-Jet A1 blends tend to have better fuel properties, with lower density and viscosity, and higher calorific values, which make them more energy-efficient and easier to handle in engines. However, WME/Jet A1 blends exhibit higher flash and fire points, making them safer in terms of combustion risks. Both biofuel types show promise in reducing environmental impacts when blended with Jet A1, with each blend offering specific advantages in fuel performance.

5. Test Engine Details:

Computerised VCR engine is used to find the performance and combustion parameters of Variable Compression Ratio Petrol Engine. The compression ratio of the engine is variable from 2.5:1 to 10:1. A unique provision is been made to vary the spark timing of the engine. Wide range of combustion studies can be conducted with the help of this setup. Engine Combustion and performance parameters like Actual volume of Air, Volumetric Efficiency, Specific fuel consumption (SFC), Brake Thermal Efficiency, Brake power, Heat Balance chart, mechanical efficiency, Frictional Power , indicated Power, PV and P-θ diagrams, Mass Fraction Burnt Angle, Estimated End of Combustion Angle (EEOC), Gross IMEP, Maximum Heat Release Rate, Maximum Heat Release rate crank angle, Maximum pressure rise rate, Maximum pressure rise rate crank angle, Maximum pressure, Maximum pressure crank angle, Start of Combustion, Total heat release, Ignition delay, ignition duration can be studied. The setup consists of single cylinder 4 stroke, VCR (variable compression ratio) electric star diesel engine connected to eddy current type dynamometer for loading. The compression ratio can be changed without altering the combustion chamber geometry by specially designed tilting cylinder block arrangement. Setup is provided with necessary instruments for combustion pressure and crank angle measurement. The set up enables the study of VCR engine performance with EGR of brake power, frictional power, BMEP, IMEP, brake thermal efficiency.

Figure 1: Test Engine Layout



International Journal for Multidisciplinary Research (IJFMR)

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Table 2: Test Engine Specifications

Engine Specifications.

Make and model	Kirloskar, TV1 make, 4-Stroke Diesel
Number of cylinders	One
Cooling system	Water-cooled
Combustion chamber	Hemispherical open type
Piston Shallow	Bowl-in type
Lubricating oil	SAE40
Compression ratio	18:1(VARIABLE)
Clearance volume, cm3	38.35
Stroke, mm	110
Connecting rod length, mm	238
Bore, mm	87.5
Displacement, cm3	661
Fuel injection pump	MICO inline, with mechanical governor
Injection type	Direct Injection
Rated power, kW	5.2
Rated speed, rpm	1500
Spray-hole diameter, mm	0.25
Valve diameter, mm	34.2
Injection pressure, bar	210
Maximum valve lift, mm	10.1
Number of Nozzle holes	3
Injection timing, CA bTDC	23°
Spray cone angle, °	110
Needle lift, mm	0.25

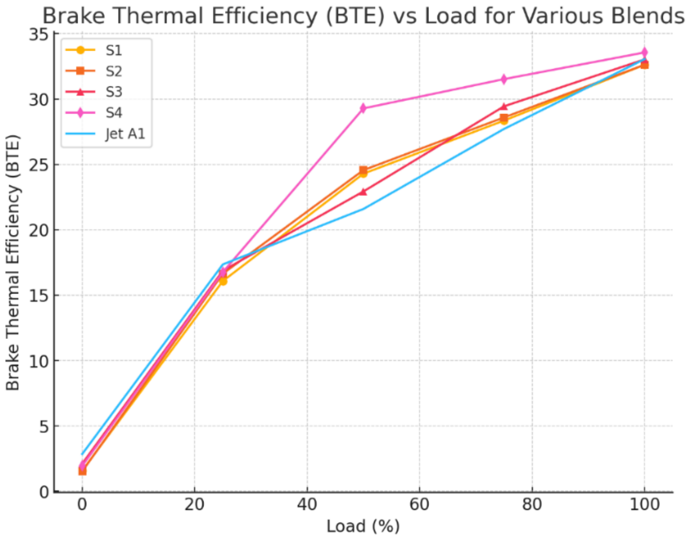
6. Result

6.1 Performance Parameters

6.1.1 Break Thermal Efficiency (BTE)

Jet A1 consistently exhibits higher Brake Thermal Efficiency (BTE) at lower loads, but its performance converges with the biofuel blends as the load increases. S3 (70:30 Jet A1/JME) starts with a slightly higher BTE at lower loads but shows more fluctuations in performance compared to the other blends. S4 (70:30 Jet A1/WME) demonstrates the highest BTE at full load (100%), indicating improved efficiency at higher load levels. S1 (80:20 Jet A1/JME) and S2 (80:20 Jet A1/WME) follow similar trends, with S2 slightly outperforming S1 at higher loads, showing moderate BTE across all load conditions.

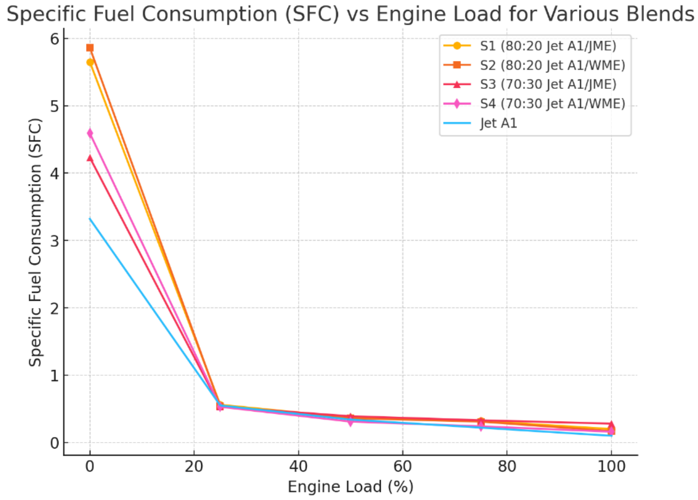
Figure 2: BTE Vs Engine Load



6.1.2 Specific Fuel Consumption (SFC)

S1 (80:20 Jet A1/JME) and S2 (80:20 Jet A1/WME) show higher SFC at zero load but gradually decrease as the load increases, with S1 slightly outperforming S2 at higher loads. S3 (70:30 Jet A1/JME) and S4 (70:30 Jet A1/WME) display a more balanced performance across different loads, with S3 having a higher SFC at higher loads. Jet A1 consistently shows the lowest SFC at all load levels, indicating superior fuel efficiency compared to the blends.

Figure 3: SFC Vs Engine Load

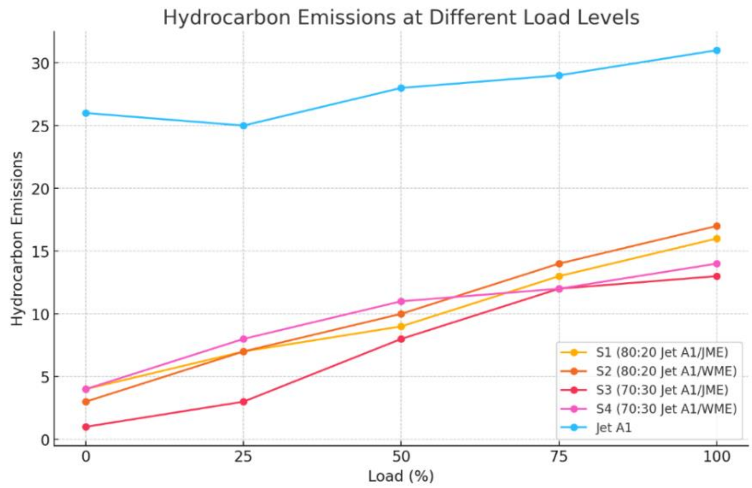


6.2 Emission Parameters

6.2.1 Hydrocarbon Emission (HC)

At 100% load, S3 (70:30 Jet A1/JME) shows the sharpest increase in hydrocarbon emissions, indicating that higher biodiesel content (30%) leads to more emissions compared to 20% blends. S2 (80:20 Jet A1/WME) and S4 (70:30 Jet A1/WME) show slightly higher emissions than their JME counterparts (S1 and S3), suggesting that WME emits more hydrocarbons than JME. Jet A1 alone has consistently higher baseline emissions but is less influenced by load changes. Overall, JME appears to burn cleaner than WME, and lower biodiesel content results in better emission control at higher loads.

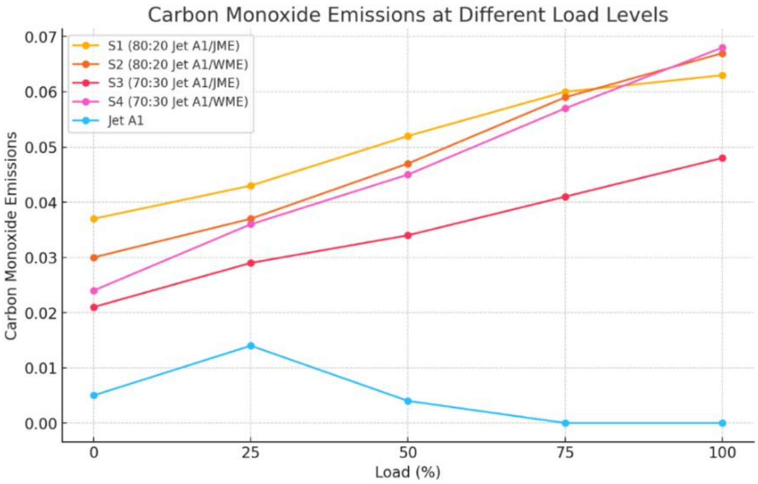
Figure 4: HC Vs Engine Load



6.2.2 Carbon Monoxide (CO)

The CO emissions show different patterns with increasing load across various fuel blends. For S1 (80:20 Jet A1/JME) and S2 (80:20 Jet A1/WME), CO emissions increase with load, with S2 generally exhibiting slightly higher levels compared to S1. S3 (70:30 Jet A1/JME) and S4 (70:30 Jet A1/WME) also show rising CO emissions, but S4 has slightly higher emissions compared to S3 at equivalent loads. JET A1 demonstrates a significantly lower CO emission profile, with minimal levels across all loads. This indicates that JET A1 is more effective in reducing CO emissions compared to the other blends, particularly at higher loads.

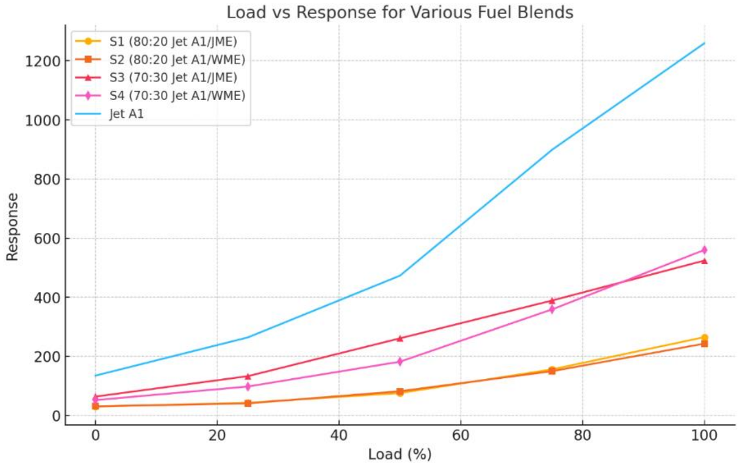
Figure 5: CO Vs Engine Load



6.2.3 Nitrous Oxide (NOx)

The NOx emissions increase with load for the different fuel blends. S1 (80:20 Jet A1/JME) and S2 (80:20 Jet A1/WME) show moderate increases in NOx emissions, with S2 generally having slightly lower emissions compared to S1 at similar loads. S3 (70:30 Jet A1/JME) and S4 (70:30 Jet A1/WME) exhibit more pronounced increases, with S4 having higher NOx emissions than S3. JET A1 consistently results in the highest NOx emissions across all loads. This indicates that while NOx emissions rise with load for all blends, JET A1 has the most significant impact, with the blend ratios affecting the emissions levels to varying extents.

Figure 6: NOx Vs Engine Load



7. CONCLUSION

This research evaluates the potential of biofuel blends in aviation by comparing the performance of Jet A1 mixed with Jatropha Methyl Ester (JME) and Waste Cooking Oil Methyl Ester (WME). The study focuses on key parameters such as Brake Thermal Efficiency (BTE), Specific Fuel Consumption (SFC), and emissions (hydrocarbon and carbon monoxide). Through analysis across various load conditions, the goal is to identify which biofuel blend provides the most efficient and environmentally friendly alternative to conventional Jet A1.

The results reveal that S1 (80:20 Jet A1/JME) emerges as the best option in terms of emissions, producing lower hydrocarbon and carbon monoxide levels while maintaining a balance in fuel efficiency. In contrast, WME-based blends, particularly S4 (70:30 Jet A1/WME), exhibit higher emissions, especially at full load, though they show improved efficiency at higher loads.

Overall, the study highlights the potential of JME as a cleaner biofuel option for aviation, with S1 offering a sustainable alternative that balances efficiency and emission reduction. This makes it a promising candidate for reducing the environmental impact of aviation fuel, paving the way for future advancements in biofuel technology.

8. REFERENCE

1. IATA (2020). Aviation and Environment: Sustainable Aviation Fuels.
2. Faaij, A. (2018). Sustainable biofuels and biomaterials: An overview. Biofuels, Bioproducts and Biorefining, 12(3), 475-489.
3. Budzianowski, W.M. (2017). Sustainable aviation biofuels. Progress in Energy and Combustion Science, 63, 19-46.
4. Kaltschmitt, M., & Hartmann, H. (2018). Energy from biomass: Fundamentals, techniques, and projects.
5. Demirbas, A. (2008). Biofuels: Securing the Planet's Future Energy Needs. Springer.
6. Knothe, G., Gerpen, J.V., & Krahl, J. (2005). The Biodiesel Handbook. AOCS Press.
7. Naik, S. N., et al. (2010). Production of first and second-generation biofuels: A comprehensive review. Renewable and Sustainable Energy Reviews, 14(2), 578-597.
8. Hubenova, Y., & Mitov, M. (2015). Second-Generation Biofuels from Biomass. Renewable Energy Resources and Policies Handbook, 239-260.
9. Lee, Y., et al. (2015). Microalgae as feedstock for biofuel production. Advances in Biochemical Engineering/Biotechnology, 153, 131-162.
10. Chisti, Y. (2007). Biodiesel from microalgae. Biotechnology Advances, 25(3), 294-306.
11. Martínez-Hernández, E. et al. (2021). Biodiesel production from waste cooking oils: A review of the chemical processes and technological advancements. Renewable and Sustainable Energy Reviews, 135, 110132.
12. Singhal, A., & Sinha, R. (2022). Biodiesel production from Jatropha curcas oil: A review on process and characterization. Journal of Cleaner Production, 332, 129991.
13. ASTM International. (2021). Standard Specification for Jet A1 Fuel. ASTM D1655.
14. IATA. (2020). Sustainable Aviation Fuel: The Key to Carbon-Neutral Growth. International Air Transport Association.
15. Kanu, N. J., Guluwadi, S., Pandey, V., & Suyambazhahan, S. (2021). Experimental Investigation of Emission Characteristics on Can-Combustor Using Jatropha Based Bio-derived Synthetic Paraffinic

Kerosene. Smart Science, 9(4), 305–316. https://doi.org/10.1080/23080477.2021.1938503
16. Aayushi Vyas, Ritika Sangode, (2021)"Production of Biodiesel from Used Cooking Oil and Jatropha Oil and Comparison Review between Properties." International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056, Volume: 08 Issue: 07.
17. G. Sujesh, S. Ganesan, S. Ramesh,(2020) "Effect of CeO2 nano powder as additive in WME-TPO blend to control toxic emissions from a light-duty diesel engine – An experimental study" Fuel, Volume 278, 118177, ISSN 0016-236, https://doi.org/10.1016/j.fuel.2020.118177
18. G Sujesh, S Ganesan, Ramesh S "Effect of compression ratio on the performance, combustion and emission of a single cylinder diesel engine using multi blended second generation biofuel." December 2019, IJMPERED.
19. Hamit Solmaz, Yakup Içingür, Alper Calam, (2014), " Investigation of the effects of civil aviation fuel Jet A1 blends on diesel engine performance and emission characteristics", Indian Journal of Engineering & Materials Science Vol. 21, April 2014, pp. 200-206.
20. Diego F. Correa, Hawthorne L. Beyer, Joseph E. Fargione, Jason D. Hill, Hugh P. Possingham, Skye R. Thomas-Hall, Peer M. Schenk,(2019) "Towards the implementation of sustainable biofuel production systems", Renewable and Sustainable Energy Reviews, Volume 107, Pages 250-263, ISSN 1364-0321, https://doi.org/10.1016/j.rser.2019.03.005.
21. G. Sujesh, S. Ramesh, (2018) " Modeling and control of diesel engines: A systematic review", Alexandria Engineering Journal, Volume 57, Issue 4, Pages 4033-4048, ISSN 1110-0168, https://doi.org/10.1016/j.aej.2018.02.011.B.
22. Gawron, T. Białecki, (2018), "Impact of a Jet A-1/HEFA blend on the performance and emission characteristics of a miniature turbojet engine". June 2018International journal of Environmental Science and Technology 15(7):1501-1508, https://doi.org/10.1007/s13762-017-1528-3