Journal of Research Administration
Society of Research Administrators International

INVESTIGATION OF PERFORMANCE AND EMISSIONS FROM JET-A1 FUEL BLENDED WITH PME AND WME

Dr. Sujesh G, Abin Babu, Ashika Ajith, Gokul V, Kailasnath KM
Department of Aeronautical Engineering, Jawaharlal College of Engineering and Technology, Palakkad, India.

Abstract: Aviation biofuels, sourced from plants or waste, are pivotal in slashing carbon emissions in aviation. As concerns mount over petroleum scarcity and limitations of electric or hydrogen tech, biofuels emerge as a greener alternative. In our project, we crafted blends of methyl esters from Palm oil and Waste vegetable oil with Jet A1, assessing various ratios to match jet fuel standards. Introducing second-generation fuels like waste cooking oil notably influenced physical traits. Producing biofuel from palm oil and waste vegetable oil presents an alternative to fossil fuels, paving the way for a lower-emission future in aviation.

1. Introduction:

The aviation sector significantly contributes to greenhouse gas (GHG) emissions, accounting for 12% of emissions from transportation and 2-3% globally. With concerns over dwindling fossil fuel reserves and escalating environmental issues, there's a notable global shift towards biomass fuel as a viable alternative. Biofuels emerge as a promising solution due to their eco-friendliness and the increasing focus on combating pollution.

Various types of biofuels, including methylesters, ethanols, and biodiesel, are being considered as alternatives to traditional fossil fuels. These biofuels offer advantages such as being non-toxic, biodegradable, and capable of reducing exhaust emissions and overall carbon dioxide emissions throughout their lifecycle.

Renewable feedstocks play a pivotal role in biofuel production, offering sustainability, recyclability, and reducing dependence on fuel-supplying countries. Primary renewable feedstocks include non-food energy crops and waste materials like cooking oils, waste wood, forest residue, and algae. Non-edible bioenergy crops like rubber tree seeds are gaining attention due to the high demand for edible oils for food purposes, presenting a viable alternative for biofuel production.

Various extraction methods, including chemical extraction, catalyst-based processes, and enzymatic processes, are employed to extract methyl esters from rubber seeds. Cost-effective and traditional methods are preferred for their practicality and efficiency.

Our research focuses on blending Jet A1 with Palm Methyl Ester (PME) and Waste Vegetable Methyl Ester (WME) to reduce fossil fuel consumption and CO2 emissions. Jet A1 is chosen as the base due to its favorable fuel properties. We aim to assess different blend ratios of PME and WME with Jet A1, ranging from 10% to 40%, and evaluate the properties and efficiency of these blends. Through this study, we aim to advocate for the adoption of biofuels in aviation, contributing to environmental sustainability and reducing the industry's carbon footprint

2.Methodology

2.1. Preparation of Palm Oil Methyl Ester

Palm oil production typically involves two main methods: milling the fruits or cold-pressing them to extract the oil. While industrial milling is common, cold-pressing yields artisanal palm oil with its natural red hue intact, often used for cooking. Regardless of the method, both milling and cold-pressing result in a mixture containing water, crude palm oil, and fruit fibres. Minimal processing is needed to extract the oil: filtering removes solids, followed by density-based separation to eliminate water. This simple process yields palm oil suitable for various applications, from cooking to industrial uses. Preparing palm oil methyl ester is essential for biodiesel production, offering a sustainable alternative to regular diesel. Transesterification initiates the process, where palm oil reacts with methanol and a catalyst like sodium or potassium hydroxide. This breaks down the triglycerides into methyl esters (biodiesel) and glycerine, a useful by-product. After transesterification, the mixture undergoes separation to isolate the methyl esters from glycerine, often through settling or centrifugation. Washing removes impurities, ensuring high-quality methyl esters. Drying follows to eliminate any remaining water, enhancing purity and stability. The resulting palm oil methyl ester is a renewable, eco-friendly fuel suitable for diesel engines with minimal modifications. It offers a sustainable solution to reduce greenhouse gas emissions and fossil fuel dependency.

2.2. Preparation of Waste cooking Oil Methyl Ester

The first step involves collecting of waste cooking oil from the university mess, primarily refined sunflower oil. The second step begins with pre-treating the mixed waste cooking oil sample, which includes physically filtering out solid impurities. Characterization is then conducted based on parameters like density and the percentage of free fatty acids (FFA). The critical parameter is the percentage of free fatty acid in the sample, with values below 4% indicating transesterification and values above 4% indicating esterification. Transesterification is chosen based on the present results of fatty acid percentage. The catalyst options are sodium hydroxide (NaOH) and potassium hydroxide (KOH), with NaOH preferred due to its higher yield compared to KOH. The mixture is left in a separating funnel for over 2 hours for glycerol to settle at the bottom, leaving behind crude biodiesel. Step three involves washing the biodiesel by mixing it with heated water (at 80°C) in a ratio of 1:1 and allowing it to settle for 10 to 20 minutes. The wash water, containing impurities, collects at the bottom of the separating funnel and is measured for various parameters. This washing process is repeated until desired parameter levels are achieved, with the optimization of wash water dependent on the molar ratio of methanol to oil.

2.3. Jet-A1

Jet A1 fuel, a meticulously refined kerosene-based aviation fuel, serves as the primary choice for turbine engine aircraft globally. Renowned for its reliability, remarkable tolerance to low temperatures, and impressive energy density, Jet A1 ensures secure and effective flight operations across diverse weather conditions. Its widespread adoption in both commercial and military aviation stems from its unwavering quality and seamless compatibility with existing aircraft engines, underscoring its pivotal role in aviation fuel standards worldwide.

2.4. Blending

Based on findings from reputable journals, it has been determined that sustainable aviation fuel can be blended with conventional jet fuels up to 50%, depending on the specific feedstock and production method employed. After careful consideration, we have opted to blend the biofuel at a ratio of up to 30%, as this ratio has demonstrated optimal performance for both palm oil methyl ester and waste vegetable oil methyl ester.

Following extensive research, we have selected three blend ratios for further investigation:

1. J70P20W10, which denotes a blend consisting of 70% Jet A1 (350ml), 20% palm oil methyl ester (100ml), and 10% waste vegetable oil methyl ester (50ml) in a total volume of 500ml.
2. J70P30, indicating a blend containing 70% Jet A1 (350ml) and 30% palm oil methyl ester (150ml) in a total volume of 500ml.
3. J70W20P10, representing a blend comprising 70% Jet A1 (350ml), 20% waste vegetable oil methyl ester (100ml), and 10% palm oil methyl ester (50ml) in a total volume of 500ml.

These blend ratios have been carefully chosen based on their potential to yield optimal performance while ensuring compatibility with existing aviation infrastructure. Our objective is to evaluate the efficacy of each blend in reducing carbon emissions and enhancing environmental sustainability within the aviation industry.

2.5. Physical Characteristics

Sl.no	Parameters	J100	J70P30	J70W20P10	J70W10P20
1	Kinematic Viscosity at 40ºC (cSt)	0.434	1.02	2.01	2.07

2	Flash point by PMCC method (ºC)	43	68	51	52
3	Fire point by PMCC method (ºC)	56	74	59	61
4	Cloud Point (°C)	-43	-16	-11	-5
5	Pour point (°C)	-53	-22	-22	-13
6	Calorific value (Cal/g)	10892.23	10675.94	10011.03	10376.03

3.Testing:

3.1. Performance and Emission Characteristics

3.1.1. Test Setup:

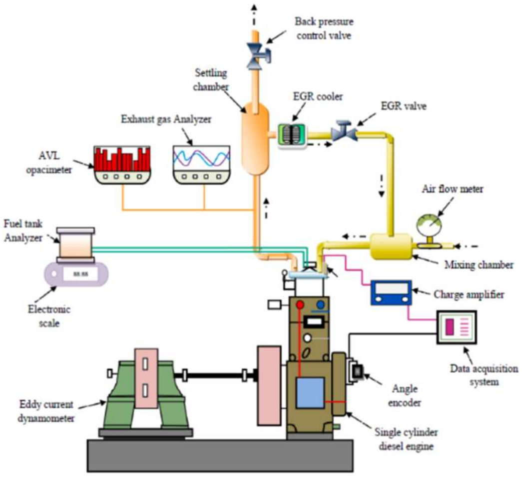


Fig 1: Experimental setup layout representation

The performance and combustion characteristics of a Variable Compression Ratio petrol engine are examined using a computerised VCR engine. This engine has the unique benefit of adjustable spark timing, allowing a compression ratio range of 2.5:1 to 10:1. This configuration makes a wide range of combustion investigations possible. Specific fuel consumption (SFC), actual air volume, volumetric 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 pressure rise rate, start of combustion, total heat release, ignition delay, and ignition duration are just a few of the performance and combustion parameters of the engine that can be thoroughly examined. This arrangement consists of an electric-start, fourstroke, and single-cylinder diesel engine with variable compression ratio connected to an eddy current type dynamometer for load adjustment. Through the use of a specifically designed tilting cylinder block mechanism, the compression ratio can be changed without altering the geometry of the combustion chamber. The system comes with all the tools needed to measure crank angle and combustion pressure. It makes it easier to investigate the performance of VCR engines with EGR, including frictional power, brake power, IMEP, BMEP, and brake thermal efficiency.

Table 2: Engine Specifications

ENGINE SPECIFICATIONS	
Product	Research Engine test setup 1 cylinder, 4 stroke, Multifuel VCR with open ECU for petrol mode (Computerized)
Product code	240PE
Engine	Type 1 cylinder, 4 stroke, water cooled, stroke 110 mm, bore 87.5 mm. Capacity 661 cc. Diesel mode: Power 3.5 KW, Speed 1500 rpm, CR range. 12:1-18:1. Injection variation:0- 25 Deg BTDC. ECU Petrol mode: Power 3.5 KW @ 1500 rpm, Speed range. 1200-1800 rpm, CR range 6:1-10:1
Dynamometer	Type eddy current, water cooled, with loading unit. ModelAG10 of Saj Test Plant Pvt Ltd.
Fuel tank	Capacity 15 lit, Type: Dual compartment, with fuel metering pipe of glass
Piezo sensor	Combustion: Range 5000 PSI, with low noise cable Diesel line: Range 5000 PSI, with low noise cable
Crank angle sensor	Resolution 1 Deg, Speed 5500 RPM with TDC pulse.
Data acquisition device	NI USB-6210, 16-bit, 250kS/s
Engine Control hardware	Fuel injector, Fuel pump, ignition coil, idle air.
Temperature sensor	Type RTD, PT100 and Thermocouple, Type K
Load indicator	Digital, Range 0-50 Kg, Supply 230VAC
Load sensor	Load cell, type strain gauge, range 0-50 Kg
Software	"Enginesoft" Engine performance analysis software
ECU software	peMonitor & peViewer software.
Make	Apex Innovations Pvt. Ltd

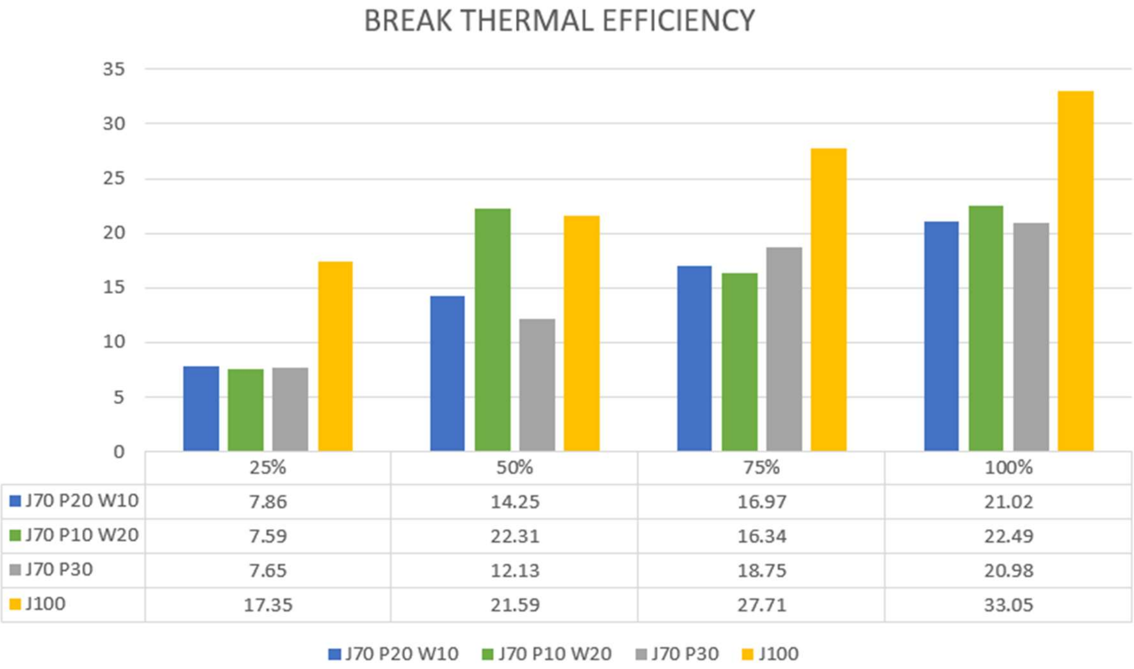
4. Result and discussion

4.1 Performance Parameters.

4.1.1. Break Thermal Efficiency

Based on our analysis, brake thermal efficiency (BTE) measures the ratio of brake power generated by an engine to the fuel energy supplied to it. Our research reveals that as the load varies, the BTE trends differ between different fuel blends and Jet A1.

Notably, at lower loads, specifically 25%, the blends demonstrate lower BTE than Jet A1. Upon increasing the load to 50%, we observed that the J70P10W20 blend exhibits similar BTE performance to Jet A1. Moving to 75% and full load conditions (100%), Jet A1 showcases higher BTE compared to the blended fuels.



	25%	50%	75%	100%
J70 P20 W10	7.86	14.25	16.97	21.02
J70 P10 W20	7.59	22.31	16.34	22.49
J70 P30	7.65	12.13	18.75	20.98
J100	17.35	21.59	27.71	33.05

Fig 3: BTE vs Load data

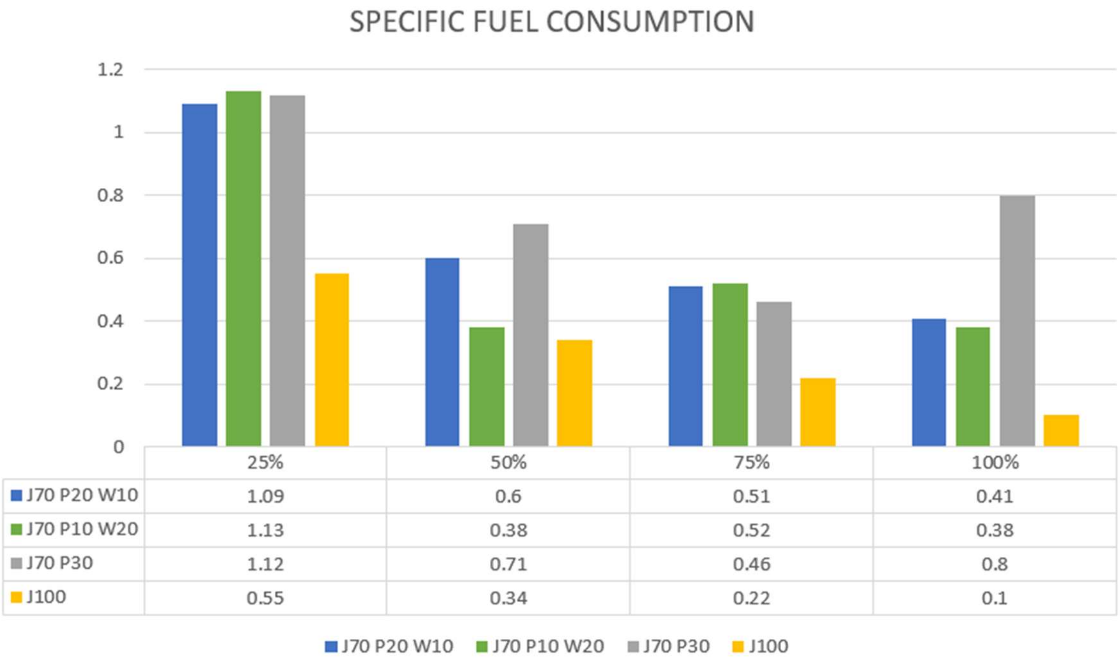
These findings suggest that certain fuel blends, particularly J70P10W20, may outperform Jet A1 at specific load levels. Further investigation and analysis are essential to fully grasp the implications of these results on overall engine efficiency and fuel consumption.

4.1.2. Specific Fuel Consumption

Specific Fuel Consumption (SFC) is a key metric indicating the amount of fuel consumed per unit of power output in an engine. It is calculated by dividing the rate of fuel consumption by the power produced or the quantity of fuel burned in unit time required to achieve a given engine output.

Upon analyzing the graph, discernible trends emerge. At a 25% load condition, SFC is notably higher compared to Jet A1. As the load increases to 50%, SFC levels become approximately higher comparable to Jet A1, with the noteworthy exception of J70P10W20, which exhibits the lowest SFC among the blends and Jet A1.

Further scrutiny at a 75% load reveals that SFC values for Jet A1 is lower than all the blends. At full load (100%), Jet A1 demonstrates a lower SFC compared to the blends. However, the blend J70P30 remains higher consumption with Jet A1 in terms of SFC.



	25%	50%	75%	100%
J70 P20 W10	1.09	0.6	0.51	0.41
J70 P10 W20	1.13	0.38	0.52	0.38
J70 P30	1.12	0.71	0.46	0.8
J100	0.55	0.34	0.22	0.1

Fig 4: SFC vs Load data

These findings highlight the potential for specific blends, particularly J70P10W20 and J70P30, to offer competitive SFC values compared to Jet A1 across varying load conditions. It is imperative to conduct further investigation to elucidate the underlying factors driving these trends and their implications for engine performance and fuel efficiency.

4.2. Emission Characteristics

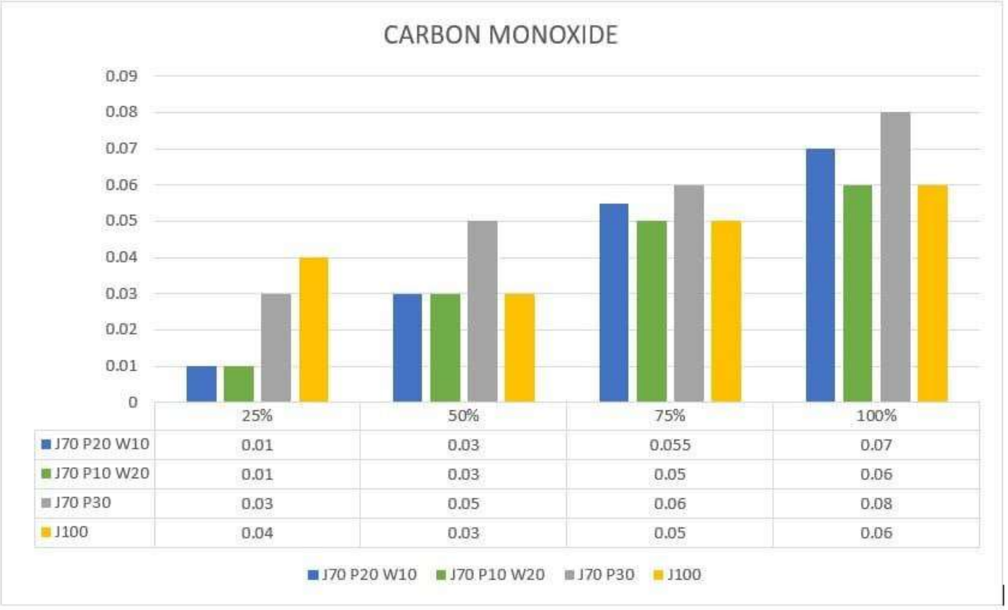
4.2.1 Carbon Monoxide

Biofuels have been recognized for their ability to generate lower carbon monoxide (CO) emissions in comparison to conventional fuels. Examination of the graph reveals that under a 100% load condition, the J70P10W20 blend consistently registers the lowest carbon monoxide emission rate among all tested blends. This trend persists even as the load is reduced, highlighting the blend's consistent performance in mitigating carbon monoxide emissions.

At a 25% load condition, Jet A1 shows higher carbon monoxide emission compared to other blends. At 50%, J70P10W20 has higher emission and both the J70P20W10 and J70P10W20 blends display similar carbon emissions. Conversely, at a 75% load condition, both the J70P10W20 and J70P20W10 shows similar emissions and at 100% J70P10W20 shows similar emission of that of jet A1.

These findings underscore the efficacy of specific blends, particularly J70P10W20 and J70P20W10, in reducing carbon monoxide emissions across varying load conditions. However, further standardization of testing procedures and comprehensive analysis are necessary to validate these observations and devise effective emission reduction strategies for the aviation industry.

Biofuels emit lower levels of carbon monoxide due to the presence of oxygen molecules within the fuel. These oxygen molecules actively participate in the combustion process by reacting with the carbon and hydrogen molecules present in the fuel. This interaction promotes more efficient and complete combustion, resulting in reduced formation of carbon monoxide during the burning of biofuels. In contrast, conventional fossil fuels lack oxygen molecules in their composition, which can lead to less efficient combustion and higher emissions of carbon monoxide. Therefore, the inclusion of oxygen molecules in biofuels significantly enhances combustion efficiency, leading to lower emissions of carbon monoxide and positioning biofuels as a greener alternative for various applications, such as transportation and energy generation.



	25%	50%	75%	100%
J70 P20 W10	0.01	0.03	0.055	0.07
J70 P10 W20	0.01	0.03	0.05	0.06
J70 P30	0.03	0.05	0.06	0.08
J100	0.04	0.03	0.05	0.06

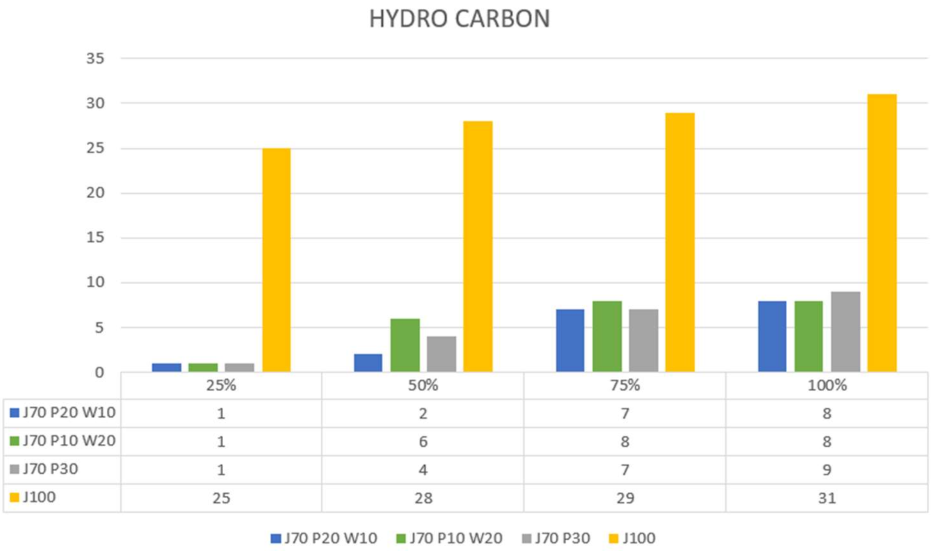
Fig 5: CO vs Load data

4.2.2. Hydrocarbon

Hydrocarbons, which consist of carbon and hydrogen molecules arranged in various combinations, are key components of fuel emissions. Upon analyzing the graph data, it is evident that the J70P20W10 blend exhibits the lowest hydrocarbon emissions at a 25% load condition. As the load increases to 50%, 75% and 100%, J70P20W10 maintains its position with the lowest hydrocarbon emissions, alongside relatively low emissions from J70P10W20. Notably, at a 100% load condition, J70P10W20 emerges with the lowest hydrocarbon emissions.

These results highlight the effectiveness of specific fuel blends, particularly J70P10W20 and J70P20W10, in curbing hydrocarbon emissions across a range of load conditions. However, further refinement and standardization of testing methodologies are necessary to corroborate these findings and develop comprehensive strategies for mitigating emissions within the aviation sector.

The reduced hydrocarbon emissions observed in the blends compared to standard fuel are attributed to the enhanced combustion process enabled by the blend composition. Notably, an increase in the percentage of ethanol within the blend correlates with a decrease in hydrocarbon emissions.



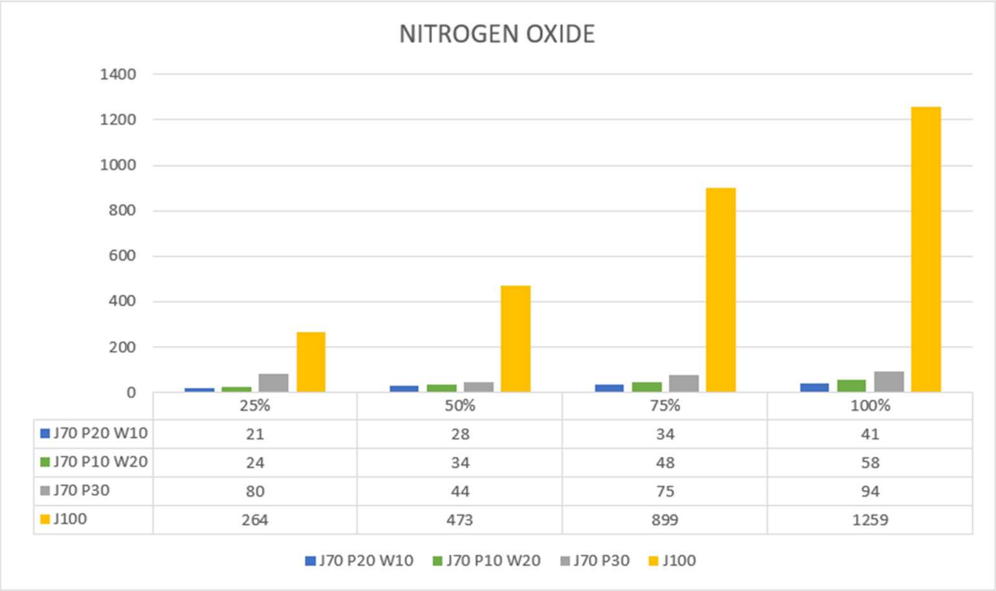
	25%	50%	75%	100%
J70 P20 W10	1	2	7	8
J70 P10 W20	1	6	8	8
J70 P30	1	4	7	9
J100	25	28	29	31

Fig 6: HC vs Load data

4.2.3. Nitrogen Oxide

Nitrogen oxides (NOx) encompass a group of gases composed of nitrogen and oxygen molecules. Upon examination of the graph data, it becomes apparent that under all load conditions, the blends exhibit lower nitrogen oxide emissions to Jet A1. Ultimately, 70P20W10 has the lowest emission among all blends.

These observations underscore the differing effectiveness of various fuel blends in reducing nitrogen oxide emissions across diverse load conditions. Further standardization of testing methodologies and comprehensive analysis are essential to substantiate these findings and devise effective strategies for mitigating nitrogen oxide emissions in the aviation industry.



	25%	50%	75%	100%
■ J70 P20 W10	21	28	34	41
■ J70 P10 W20	24	34	48	58
■ J70 P30	80	44	75	94
■ J100	264	473	899	1259

Fig 7: NOx vs Load data

Conclusion:

The blending of Palm Methyl Ester (PME), Waste Vegetable Methyl Ester (WME), and Jet A1 fuel presents a promising alternative to traditional aviation fuels. Research indicates that this blend offers notable reductions in nitrogen oxide (nox) and hydrocarbon (HC) emissions compared to conventional fuels. All the blends shows satisfactory values, except carbon monoxide emissions which has higher emissions than Jet A1.

Among our blend formulations, the J70P10W20 blend stands out for its superior emission characteristics in comparison to other blends relative to Jet A1. This suggests that the J70P10W20 blend may offer a favorable balance between environmental impact and performance, making it a compelling option for reducing emissions in aviation applications.

Continued research and development efforts are essential to further optimize these blend formulations and maximize their environmental and performance benefits. Additionally, comprehensive testing and analysis will be crucial to validate these findings and ensure the viability of PME-WME-Jet A1 blends as a sustainable solution for the aviation industry.

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