Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi, 14(1), 377-389, 2024
Journal of the Institute of Science and Technology, 14(1), 377-389, 2024
ISSN: 2146-0574, eISSN: 2536-4618
Makina Mühendisliği / *Mechanical Engineering* **DOI: 10.21597/jist.1375703**
Araştırma Makalesi / *Research Article*
Geliş tarihi / *Received*: 13.10.2023 **Kabul tarihi / *Accepted*: 02.01.2024**

Atıf İçin: Taşyürek, M. ve Şen, S. (2024). Mini Jet Motorunda Aspir Metil Ester-Jet A1 Karışımlarının Kullanımının Motor Performansı ve Emisyonlara Etkisinin Deneysel Olarak İncelenmesi. *Iğdır Üniversitesi Fen Bilimleri Enstitüsü Dergisi*, 14(1), 377-389.

To Cite: Taşyürek, M. & Şen, S. (2024). Experimental Investigation of The Effect of Using Safflower Methyl Ester-Jet A1 Blends on Engine Performance and Emissions in Mini Jet Engine. *Journal of the Institute of Science and Technology*, 14(1), 377-389.

Mini Gaz Türbini (MGT) Motorunda Aspir Metil Ester-Jet A1 Karışımlarının Kullanımının Performans ve Emisyonlara Etkisinin Araştırılması

Mustafa TAŞYÜREK[1*] , Soner ŞEN[1]

Öne Çıkanlar:
- İlk defa aspir bitkisi bazlı bio jet uygulaması gerçekleştirildi
- Tüm uçuş koşullarını simüle edecek motor devir sonuçları belirlendi
- Gerçek küçük ölçekli bir jet (MGT) motoru deneyi yapıldı

Anahtar Kelimeler:
- Havacılık yakıtları
- Emisyon
- Jet a1
- Jet motoru
- Aspir metil esteri

ÖZET:

Bu çalışma, Aspir Metil Esteri-Jet A1 karışımının küçük ölçekli bir jet motorunun itme performansı, yakıt tüketimi ve kirletici emisyonları üzerindeki etkisinin ve ayrıca Jet A1 yakıtına aspir metil esterinin (SME) alternatifinin araştırılmasına odaklanmıştır. Deneyler, Jet A1 ile aspir yağından üretilen yakıtın karıştırılmasıyla elde edilen biyojet yakıtlarının bir jet motorunun taksi, yaklaşma, tırmanma ve kalkış güç çevrimlerinde kullanılmasıyla gerçekleştirilmiştir. Uçağın gerçek çalışma şartlarındaki yüzde güç değerlerinden elde edilen her iki yakıt tipinin itme kuvvetleri belirlenmiş ve buna göre CO, HC, CO_2 emisyonları, yakıt tüketimi ve egzoz gazı sıcaklığı ölçümleri yapılmıştır. Yapılan ölçümler sonucunda biyojet kullanımıyla itkide yaklaşık %27.5 oranında azalma görülmüştür. Ayrıca HC emisyonları %51'e kadar azalırken CO emisyonu düşük devirlerde birbirine daha yakınken tam güçte % 30 artmıştır. Metil esterin CO_2 emisyonu devir değişikliğine göre % 8-16 arası artış gösterirken, yakıt tüketimi düşük devirlerde kabul edilebilir düzeyde iken tam güçte % 50'yi aşmıştır.

Experimental Investigation of the Effect of Using Safflower Methyl Ester-Jet A1 Blends on Engine Performance and Emissions in Mini Jet Engine

Highlights:
- For the first time, a safflower plant-based bio jet application was carried out
- Engine speed results that will simulate all flight conditions have been determined
- A real small-scale jet engine experiment has been conducted

Keywords:
- Aviation fuels
- Emission
- Jet a1
- Jet engine
- Safflower methyl ester

ABSTRACT:

This study focused on the investigation of the effect of the SME-Jet A1 mixture on the thrust performance, fuel consumption and pollutant emissions of a small-scale jet engine, also the alternative of safflower methyl ester (SME) to Jet A1 fuel. The experiments were carried out by using bio jet fuels obtained by mixing Jet A1 and the fuel produced from safflower oil in taxi, approach, climb and take-off power cycles of a jet engine. The thrust forces of both types of fuel obtained from the percentage power values of the aircraft under real operating conditions were determined and accordingly CO, HC, CO_2 emissions, fuel consumption and exhaust gas temperature measurements were made. As a result of the measurements, approximately 27.5% reduction in thrust was observed with the use of biojet. In addition, HC emissions decreased by up to 51%, while CO emissions increased by 30% at take off while being closer to each other at low rpm. While the CO_2 emissions of methyl ester increased by 8-16% depending on the speed change, fuel consumption, while at an acceptable level at low rpm, exceeded 50% at take off.

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INTRODUCTION

Gas turbine engines have become an indispensable power source for aircraft as they have high power/volume ratios. Turbojet, turboprop or turbofan engines consume traditional fossil-based petroleum fuels that are required by their engine cycles. The high power requirements of aircraft are causing the air transport industry to use large amounts of fossil-based petroleum fuels. In addition, since the high-power requirements of aircraft cannot be met by other alternative energy sources such as electrical energy, it is not possible to find an alternative energy source to fossil fuel use.

There are concerns about the cost of traditional fuels, the increase in pollutant emissions into the environment and energy security (Xue, Hui, Singh, & Sung, 2017). Because of these obligations, the development of alternative fuels from renewable plant sources has attracted great attention, primarily for use in road vehicles, and the successful results have paved the way for their use in aircraft as well. Plant-derived alternative fuels can be made available in a worldwide supply chain system by judicious blending with petroleum-based aviation fuels, with existing fuel supply infrastructure. (Sani, 2018). Considering that fossil fuels will run out in about 50-60 years in the future production, alternative fuels to jet fuel must be found or produced for aircraft already. This is the main reason for the focus on the use of biologically sourced jet fuels in recent years. It is thought that fossil-based fuel properties can be added to bio-fuels in the near future (Enagi, Al-Attab, & Zainal, 2018; Gupta, Rehman, & Sarviya, 2010; Knothe & Razon, 2017; Rehan et al., 2018; Živković et al., 2017). Also, alternative fuels produced from renewable biomass are very important as they potentially provide cleaner combustion and have a sustainable supply of raw materials from existing fields (Nigam & Singh, 2011). Aviation greenhouse gas emissions can be reduced thanks to the savings achieved during the production phase of renewable biological materials and their conversion into fuels.

In today's conditions, mixing and using biological fuel in certain proportions in aircraft will prevent the consumption of a significant amount of fossil fuels and will create an alternative fuel production for the future. The use of jet fuels obtained by mixing biofuels, which is required by civil aviation authorities, will become more widespread. In this context, researchers have focused their studies on alcohol and oil esters, which can become alternative bio-jet fuels in the last decade. However, due to the risk of damage to the turbine in gas turbine engines, much less experimental work has been done using full-size gas turbine engines (Allouis et al., 2010; Chiaramonti et al., 2013; Corporan et al., 2005; Habib, Parthasarathy, & Gollahalli, 2010; Lupandin, Thamburaj, & Nikolayev, 2005; Moore et al., 2017; Nascimento et al., 2008).

Hemighaus et al. (Hemighaus et al., 2006) investigated the use of a wide range of alternative fuels such as ethanol, methanol and fatty acid methyl ester in gas turbine engines and demonstrated their usability as alternative fuels. Manigandan et al. reported that the oxygen content and fuel atomization of the fuels used in gas turbine engines are important parameters in the formation of less polluting emissions and higher combustion rates (Manigandan, Atabani, Ponnusamy, & Gunasekar, 2020). In this study, safflower methyl ester and JET-A1 fuel were mixed in certain proportions and burned in a micro gas turbine engine under different engine loads, and as a result, the combustion, performance and emission parameters of the fuels were examined. In the study, they reported that the fuel consumption, which varies depending on the thrust, decreased by 41%, it was observed that the fuel mixtures produced less NOx, CO and HC emissions compared to Jet-A fuel. A similar result found by Wang et al. was obtained with mixing the biofuel from camelina oil - JP-8 jet fuel (Wang, Feser, Lei, & Gupta, 2020). In their study, they achieved up to 50% reduction in CO emissions of the blend fuel compared to the JP-8 fuel.

Habib et al. (Habib et al., 2010) reported the performance and emissions obtained by burning soybean methyl ester, canola methyl ester, recycled rapeseed methyl ester, animal fat biofuel and bio jet fuels obtained by mixing them with 50% Jet A in a 30 kW small-scale gas turbine engine. They compared its properties with the values of crude jet A fuel. Although biofuel blends reduce the thrust force, it has been observed that they reduce thrust specific fuel consumption. In addition, although there was no significant difference in exhaust gas temperature between the fuels used, it was observed that the use of biofuels reduced the CO and NOx emissions.

To understand its flammability as a potential biofuel, Akinyemi et al.; (Akinyemi, Jiang, Hernandez, McIntyre, & Holmes, 2019) burned algal oil in a laboratory-scale gas turbine burner and examined visual flame images, gas temperature, carbon monoxide (CO) and nitrogen oxide (NOx) emissions at the combustion chamber exit. The study emphasized that the viscosity of oils is very high compared to that of diesel fuel, and that clean combustion is due to low viscosity, which is the cause of fine spray combustion. They also reported that reducing emission values can be achieved with fine droplets. Sundararaj et al. (Sundararaj et al., 2019) examined the emission values of jatropha and camelina biofuel in a laboratory-scale gas turbine engine. In the study, they reported that NO_X emission increased and CO emission decreased due to increasing flame temperature. In another study, (EL-Zohairy, Attia, Huzayyin, & EL-Seesy, 2023) lower HC emissions compared to Jet A1 fuel were obtained as a result of improving spray and atomization levels by adding diethyl ether to biofuel produced from waste frying oil. In another study; (Kumar, Karmakar, & Nimesh, 2024), alternative fuel research has been conducted in both internal combustion engines and gas turbine engines. In the study, it was said that increasing viscosity, high density and aromatic content may increase CO emissions, while decreasing it may increase CO_2 emissions. In addition, it is emphasized that viscosity has the highest importance in the formation of CO emissions and hydrogen content in the formation of CO_2 emissions.

The use of biofuels obtained from jojoba oil and palm oil by transesterification method with jet fuel in different proportions in gas turbine engine was studied (El-Zoheiry, EL-Seesy, Attia, He, & El-Batsh, 2020; Talero et al., 2020). As the percentage of jojoba additive increased, a decrease in NOx and an increase in CO and UHC were observed. In the experiments using palm oil, it was observed that as the biofuel ratio increased, the thrust force decreased significantly, the CO and HC emissions decreased similarly, and the fuel consumption increased. In addition, when the biofuel spray flame structure was examined, it was seen in the study of Chong and Hochgreb (Chong & Hochgreb, 2014) that rapeseed biofuel offered larger droplet size, higher droplet number density and volumetric flux. This shows that the evaporation property of biofuels in general is not as good as Jet A1 fuel due to their high viscosity and low volatility. Kumar & Karmakar said that the physical properties of fuels are important in the selection of alternative aviation fuels. They emphasized that the aromatic contents and viscosities of fuels will affect their combustion properties and emissions, and therefore combustion performance (Kumar & Karmakar, 2020).

Looking at the literature, it has become a starting point for the future study as a bio jet source, as it is possible to grow it in non-agricultural areas due to the limited academic research on the safflower plant, the safflower plant is an oilseed plant that can be grown easily and is a drought-resistant plant. In addition, the fuel properties of safflower methyl ester (SME) allow it to be mixed with fossil-sourced jet fuel in certain proportions. For all these reasons, the experimental investigation of the thrust performance and pollutant gas emission characteristics of the bio jet fuel obtained by using a certain amount of SME for the real power ratio values (taxi-approach-take-off-climb) that has never been studied before is the focus of our study.

MATERIALS AND METHOD

Fuels Used In Experiments

Jet-A1 fuel used in commercial aircraft and methyl ester obtained from safflower oil were used in the experiments. SME is produced from safflower oil by applying transesterification procedures (mixing, heating, methoxide addition, washing and boiling steps). The methyl ester obtained does not contain any undesirable substances such as glycerin, alcohol or water left as residue by the process processes. SME-JetA1 blend bio jet was prepared at a rate of 7.5% according to the future production, considering the international use requirement. The fuels in the glass beaker were mechanically mixed at room temperature and did not undergo any retention period. Bio jet preparation processes were carried out in the Aircraft Maintenance Workshop of Selçuk University Civil Aviation School. Various fuel properties of Jet A1 and SME fuels are shown in Table 1.

Table 1. Properties of SME biodiesel and Jet A1 fuels. Measured by experiments and gathered values from the literature (Pratap Singh & Agarwal, 2016)

Properties/fuels	Jet A1	SME
Density (g/cm^3, 15 °C)	0.775	0.800
Viscosity (cSt)	3.87 (-20 °C)	4.029 (40 °C)
Lower calorific value (kcal/kg)	10200	8837.5
Flash Point (°C)	38	180
Freezing Point (°C)	-47	-11
Cetane number	42	49.8
Oxygen content (mg/L)	0	4.25

The oxygen content of the mixture formed by the addition of SME increased compared to Jet A1, but its calorific value decreased. In addition, the viscosity increased due to the density difference caused by the addition of SME. Because the average lower heating values of biofuels are approximately 11% lower than Jet A1 fuel.

Turbo-Jet Gas Turbine Engine

To investigate the effect of biofuel - Jet A1 fuel mixture on the thrust performance and pollutant emissions of a gas turbine engine, a small-scale jet engine test set with a maximum thrust of 160N was used in the aircraft engine maintenance laboratory of Selçuk University Civil Aviation School. CO, CO_2 and HC measurement data were also obtained with the OVLT 3040 emission measurement device. Considering the high fuel consumption of gas turbine engines, it was decided to use the miniature for hobby and educational purposes. The engine used is the JetCat P160-RXi-B mini-scale turbine engine. The technical information of the jet engine used in the study is presented in Table 2.

Table 2. Technical properties of the small-scale jet engine

Jet Engine Specifications	Values
Design max thrust (N)	160
Compression ratio	3.1/1
Specific fuel consumption (ml/min)	520
Compressor type	Single stage radial
Turbine type	Single stage axial
Engine weight (g)	1530
Diameter (mm)	112
Length (mm)	285
RPM range (idle-max)	33.000-123.000

In the experiments, an instantaneous fuel consumption flowmeter, load cell-transmitter and K-type thermocouple were used to measure fuel consumption, static thrust, and exhaust gas temperature, respectively. Also, specially designed exhaust nozzle, sample probe and emission analyzer were used for emission measurement, hall-effect rpm sensor was used for engine speed measurement and also ECU-pc and ardunio-pc hardware software kits were used for data collection, recording and engine control. Thus, the operation control of the motor, measurement and data collection processes could be done via the PC. In order to measure the static thrust data without loss, a linear roller bearing assembly that will create minimum friction has been designed. In addition, the temperature, pressure, and humidity values of the environment where the experiments were carried out were recorded. The schematic representation of the experimental set is presented in Figure 1.

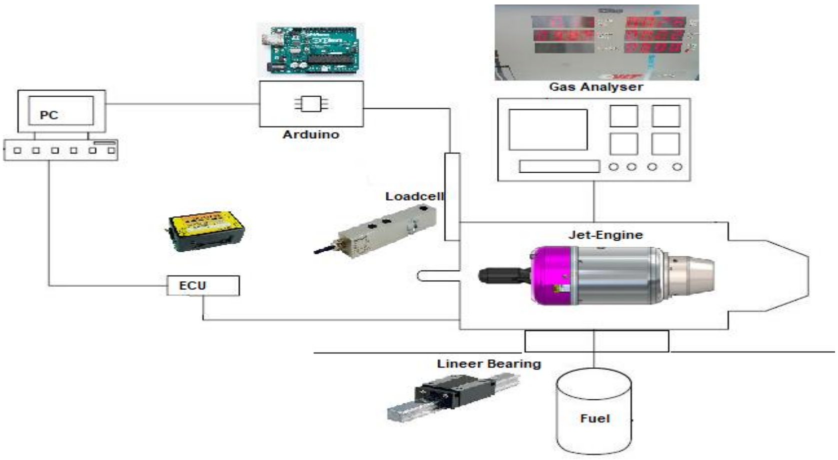

Figure 1. Schematic representation of the experiment set

In order to minimize the damage to the fuel system and engine components of the biofuels used for a long time and to extend the engine life, the experimental engine was heated using Jet-A1 fuel before each experiment. In addition, after the biofuel experiments, the engine was run in idle state for 5 min using pure Jet-A1 fuel.

Preparation of Biojet Fuel

Safflower methyl ester was obtained by transesterification method from safflower oil purchased as cold-pressed. Vegetable oil, methanol and sodium hydroxide (NaOH) were used in the chemical process. Vegetable oil/methanol ratio is obtained 20% by volumetric. The catalyst was added at 5 g per liter of oil. First, methoxide was formed by dissolving NaOH in methanol. Then, this methoxide was added to safflower oil heated to 60 °C and blend it at 600 rpm for 2 hours. Methanol was recovered with the condensation integrated into the mechanism, and after blending with Jet A1, the methyl ester viscosity value was reached to ensure proper combustion in the MGT. After the blending stage, the blend was transferred to the fuel separation and the glycerin was settled in a waiting phase for precipitation. After phase separation, washing was done with pure water to remove trace amounts of foreign matter remaining in the fuel. In the last stage, Boiling was applied to completely remove the washing water after separation. SME was obtained by filtering after a heating temperature of 105 °C.

Experimental Procedure

During the experiments, for contains actual flight conditions determined by ICAO, 7%, 30%, 85% and 100% power values were taken as basis for taxi, approach, climb and take-off situations used during the flight of aircraft (Masiol & Harrison, 2014; Tasca, Cipolla, Abu Salem, & Puccini, 2021).

Accordingly, the throttle was adjusted for the engine used in the experiments, and the number of revolutions corresponding to the percent power values were determined by using Jet A1 fuel. Performance-emission data were determined by adjusting the same cycle numbers in subsequent bio jet experiments. Each experiment was repeated three times, and the analytical averages of the results were calculated. Additionally, it is frequently emphasized in the literature that ICAO should also consider the times spent in a typical LTO cycle of an aircraft in order to interpret the advantages and disadvantages of pollutant gas emissions (Hespanhol, de Sá, & Fortes, 2014; Yunos, Ghafir, & Wahab, 2017). The amount of emissions generated during the LTO cycle is proportional to the time spent in each mode (Albisinni, 2016; Chilongola & Ahyudanari, 2019; Masiol & Harrison, 2014).

The uncertainty analysis of the experimental study (Holman, 2001) was performed. Since the same measuring devices and experimental procedure were applied in the study, a single experimental uncertainty was calculated depending on the measuring devices and other errors. The total uncertainty values of the measured and calculated parameters are given in Table 3.

Table 3. Uncertainties of the experiments.

Parameter	Measuring range	Uncertainty
Static thrust (N)	0-250	±0.019
Fuel consumption (ml/min)	1000	±0.020
EGT (ºC)	15-1100	±0.001
Carbon monoxide (% Vol)	0-0.5	±0.002
Carbon dioxide (%Vol)	0-10	±0.002
Hydrocarbon (ppm)	0-500	±0.020

RESULTS AND DISCUSSION

Thermal Efficiency

The ratio of the unit net work produced to the energy obtained by burning unit fuel mass is called thermal efficiency. Thermal efficiency changes are presented in Figure 2. As seen in Figure 2, it is observed that the addition of biofuel to Jet-A1 fuel reduces thermal efficiency under all load conditions. This is due to the lower calorific value of the biofuel blends compared to Jet A-1 fuel and the decrease in combustion efficiency.

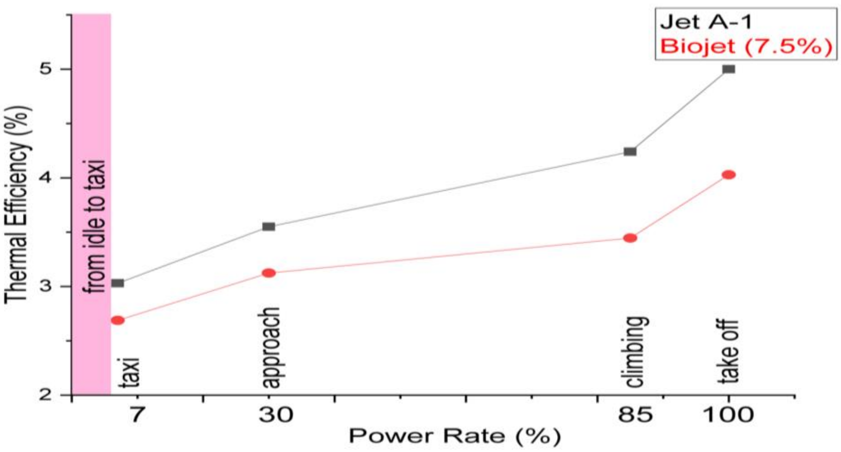

Figure 2. The effect of biojet blend on thermal efficiency

Static Thrust

In order to examine the static thrust performance values of bio-jet and pure jet fuel in taxi, approach, take-off and climb situations, experiments were carried out at predetermined power cycles and the obtained thrust values are presented in Figure 3. Figure 3. shows that the biofuel mixture has a maximum reducing effect of 8% on the thrust at partial loads, but a serious reduction of 27% occurs at full load. This is explained by the fact that the increase in engine speed causes delays in the combustion of the biofuel mixture, the addition of biofuel makes fuel evaporation more difficult, and the combustion spreads over a longer distance and the fuel energy is dissipated in the exhaust nozzle after the turbine. This is also confirmed by the increase in exhaust gas temperature, which will be explained in the next section. With the increase in EGT, the time required for biofuel to burn at high speeds is shortened (Sarıkoç, Ünalan, & Örs, 2019). This also plays a role in reducing thrust.

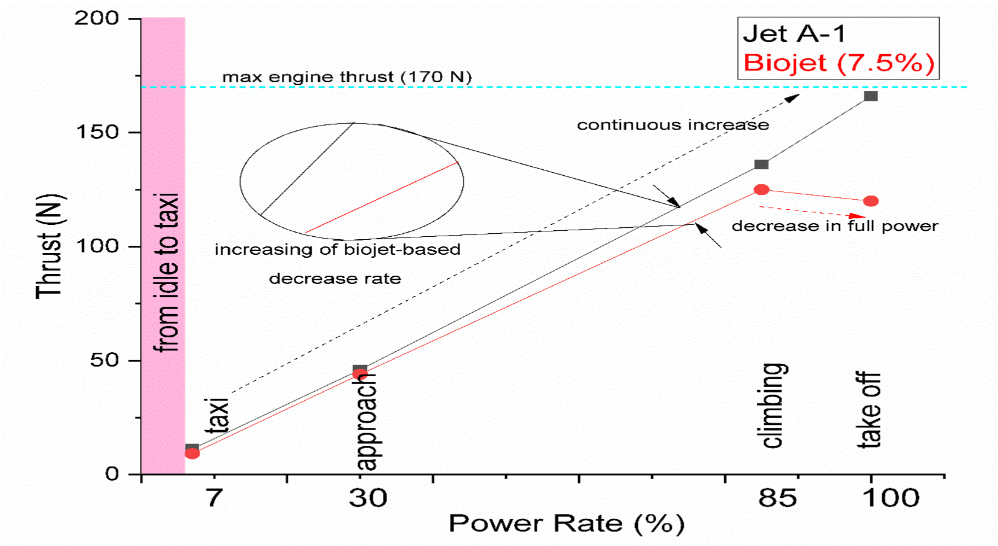

Figure 3. The effect of bio jet at different power ratios on thrust force

Thrust Specific Fuel Consumption (TSFC)

The total fuel consumption required for unit thrust (1N) is called thrust specific fuel consumption (TSFC). The TSFC values obtained in the experiments for biofuel mixed and pure Jet A fuel for different load conditions are given in Figure 4. Considering Figure 4., in the experiments using Jet A1 fuel in accordance with the characteristics of jet engines, it is seen that the TSFC value decreases with the increase of the speed. In other words, the fuel consumption required to generate the unit thrust decreases, so the thermal efficiency increases.

For the bio jet experiments obtained with the biofuel blends, while the TSFC values decreased in accordance with the engine characteristics at partial loads, an increase occurred in the full load condition. This increase is 58.1% for the full load condition compared to pure Jet A fuel. SME's TSFC value increased only by around 20% in Taxi and approach powers. Considering all the experiments, it has been seen that more fuel is needed for the unit thrust in the experiments with the biofuel blends, so biofuel reduces the thermal efficiency.

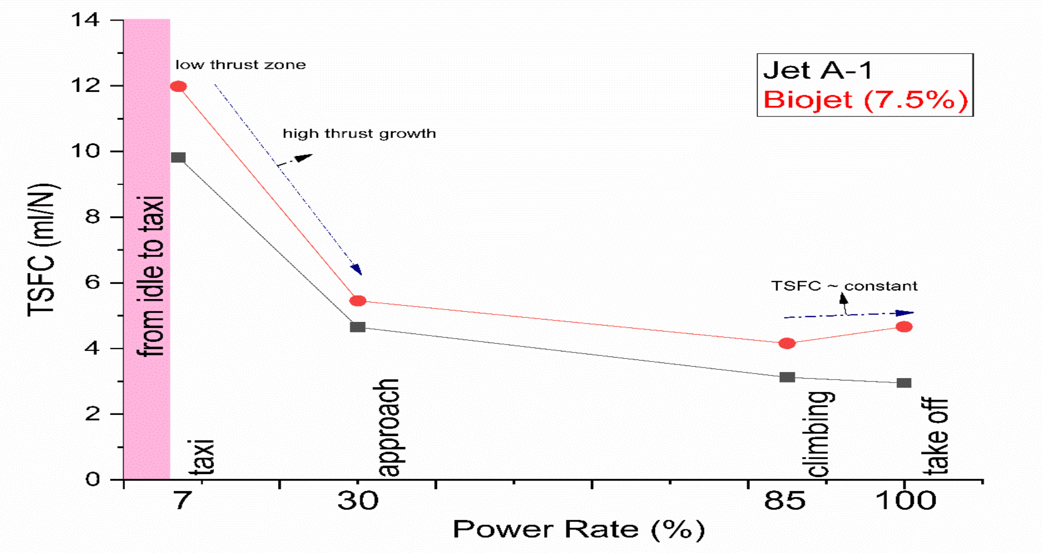

Figure 4. The effect of bio jet at different power ratios on TSFC

Exhaust Gas Temperature (EGT)

Exhaust gas temperature (EGT) values of both Jet A1 and biojet fuels for different load conditions are given in Figure 5. The EGT values of the bio jet at all load conditions resulted in higher temperatures than the Jet A1 fuel EGT values between 624 °C and 693 °C. The EGT values of SME are generally close to those of Jet A 1. The difference, which does not exceed 3% in taxi, approach and climbing speeds, increases to 8% in take-off condition, while the full engine load. The temperature increase is due to the lack of time required for the combustion of the biofuel mixture at high revs, thus spreading the combustion to the exhaust area. Additionally, when biodiesel blended fuels are used in engines, the amount of fuel required to obtain the required output (thrust) power increases (Killol, Reddy, Paruvada, & Murugan, 2019). Occurrence of combustion in this way reduces the ability of high-energy exhaust gases to do work, reduces thrust, reduces thermal efficiency, and causes high-energy gases, thus, high temperatures.

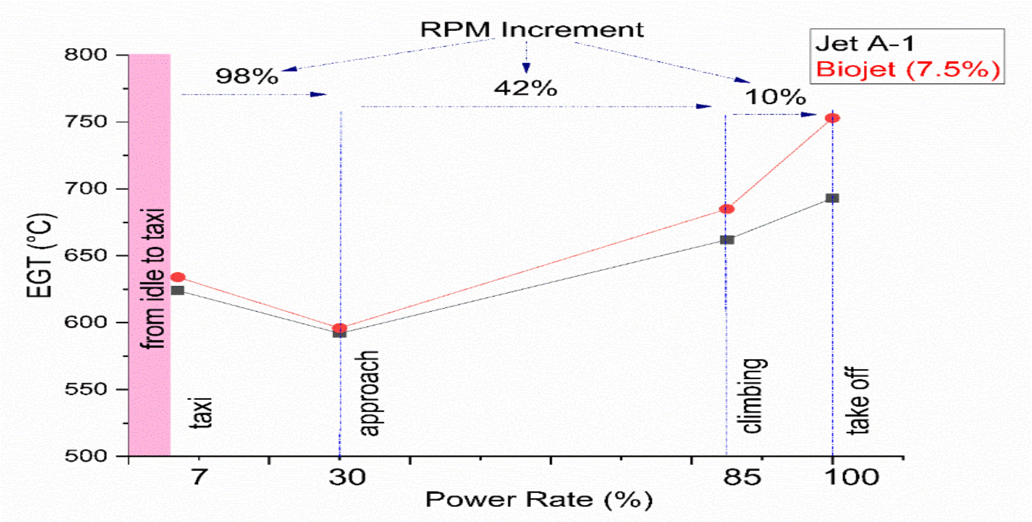

Figure 5. The effect of bio jet at different power ratios on exhaust gas temperature

Although the combustion chamber exit temperatures exceed 800 °C, the values were measured approximately 100 °C - 150 °C lower due to the temperature measurement made from the exhaust nozzle in the outlet section, the expansion of the gases and the temperature decrease in the turbine section.

Emission Measurements

The absence of carbon monoxide (CO) and the presence of carbon dioxide (CO_2) in emission measurements are indicators of complete combustion in the engine. In Figure 6, CO_2 emission values are given for different power ratios. The maximum CO_2 emissions were observed at take off rpm both Jet A1 and safflower biojet. The measured CO_2 concentration gradually increased in parallel with the increase in revolutions due to the enormous amount of air entering the turbine. In taxi and approach cycles, in bio jet application, the CO_2 concentration in the exhaust did not change significantly compared to the value of Jet A. While it varied between 3-15% in taxi and approach periods, this increase was around 30% at full power. Biofuels have more carbon atoms compared to petroleum-derived fuels. As a result of the high number of carbon atoms in biofuels, adding 7.5% safflower methyl ester to Jet A1 caused an increase in CO_2 emissions.

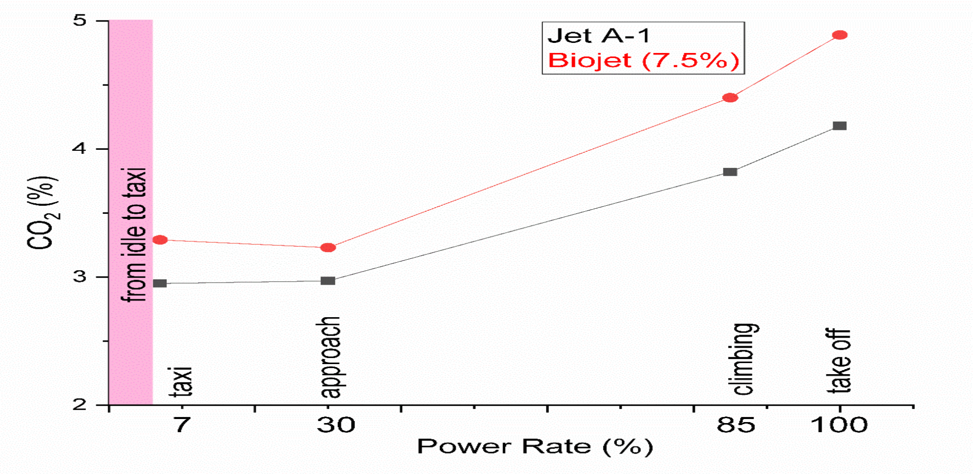

Figure 6. The effect of bio jet at different power ratios on CO_2 emission

With the addition of biofuel, CO emission showed higher values in acceleration and full power conditions, as well as giving values close to the data of Jet A fuel at low speeds. This increase was 45% in the 85% power applied, which is the power given at the climbing of the aircraft. Basically, this increase in CO emissions is due to the different combustion modes between jet fuel and SME-jet fuel blends. This resulted in a more homogeneous and therefore more complete combustion of Jet A1 fuel, resulting in a reduction in CO emissions. The presence of oxygen in the fuel reduces the rate of soot formation and increases the oxidation rate of soot in downstream regions, resulting in higher CO concentrations. In addition, the increase in viscosity because of mixing the biofuel using SME with Jet A1 creates a heterogeneous combustion mode effect since the fuel cannot evaporate completely and increases the droplet size. This negatively affects CO emissions. The graph of CO varying with the thrust forces obtained according to the changed engine revolutions under the same conditions is given in Figure 7.

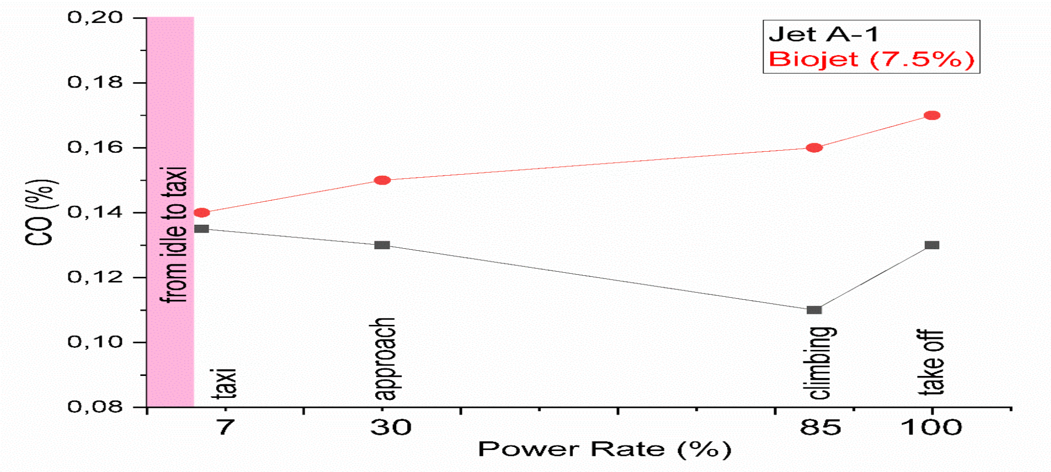

Figure 7. The effect of bio jet at different power ratios on CO emission

As seen in the figure, the CO emission values of the whole biofuel (7.5% vol) - Jet A1 mixture are higher than the pure Jet A1 fuel values. It may be observed that the CO values of biofuel-added fuels are higher than the CO values of conventional fuels under some conditions (El-Zoheiry et al., 2020). This situation can be attributed to both the inability to achieve homogeneous combustion in Jet A1 fuel and the low flame temperature. For this reason, the increase in the exhaust gas temperature under the condition of burning 7.5% biofuel increased the CO ratio especially at high revs.

There are different parameters that affect the production of unburned hydrocarbon, including poor atomization, low combustion rate, fuel-air mixing power, combustion mode (homogeneous or heterogeneous), quenching of combustion products, and the formation of partially large fuel droplets. In addition to other emission parameters, unburned hydrocarbon measurement is required to better understand the combustion of fuel with and without a biofuel blend. Figure 8 shows the HC emission distribution for pure jet A1 fuel and SME/jet A1 bio jet fuel. As seen in Figure 8, while the HC reduction percentage was approximately 34-37% respectively in the taxi and approach powers, this decrease rate increased to 45% in the climbing. In full power mode, a 51% reduction was detected. HC values are compatible with the amount of CO_2. After the taxi revolution, the HC amounts of both fuels decreased. This is due to the decrease in specific fuel consumption (Özçelik, Aydoğan, & Acaroğlu, 2015).

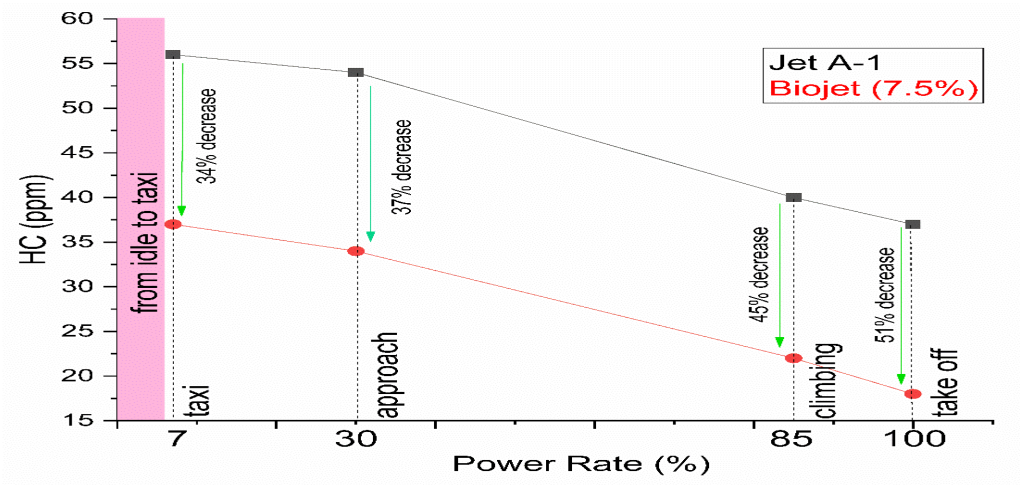

Figure 8. The effect of bio jet at different power ratios on unburned HC emission

CONCLUSIONS

It is clear that the use of petroleum derivative fuels as an energy source for the aviation industry will continue for a long time. For this reason, it is predicted that the use of petroleum alternative fuels even in small amounts will cause great savings and serious positive changes on emissions. With the experimental study, the effects of a biofuel, which can be an alternative to Jet A1, on the performance and emissions have been investigated in the real power ratios of the aircraft. The results obtained can be summarized as follows:

- While the addition of safflower methyl ester-based fuel to the Jet A1 caused a thrust reduction of 4-18% in taxi, approach and climb power rates, this rate suddenly increased to 27% during the takeoff phase. Thus, it appears that the SME fuel addition is usable at part loads.
- With the addition of SME fuel to Jet A1 fuel, TSFC increase was observed in all load values, but the increase in full load condition was 58.1%. This increase remained between 17-22% in taxi and approach powers. This shows that SME bio jet fuel has a reducing effect on thermal efficiency at all loads.
- Although the exhaust gas temperature of the turbojet engine increased slightly with the addition of biofuel, it was observed that this increase was not at a rate that would damage the engine, but the spread of combustion to the exhaust nozzle outlet caused a decrease in efficiency. The temperature increase was 60 degrees only at take off power. There was only an insignificant change of 4 degrees in approach rpm.
- In experiments under partial load, it was observed that the addition of biofuel did not cause a significant increase in CO_2, but a significant increase occurred at full load. However, the negative effect of biofuel on combustion performance resulted in an increase in CO emissions in all load cases. Again, the data in approach power are the closest data to each other with a CO_2 value of 0.26 %.
- As a result of mixing SME biofuel with Jet A1 fuel, there was a significant reduction in unburned HC emissions. It is also stated in the literature that this situation is one of the most important effects of biofuels. The reduction rate was 34% in the taxi state and 51% at full power.
- When all experimental results are examined; for partial load situations, it is predicted that SME biofuel can be successfully added to petroleum-based fuels and reduced fossil-based fuel consumption. However, engine fuel assemblies need to be developed that enable the use of pure Jet A1 in the take-off state at full load.
- Among the many oilseed plants, those that cannot be used for food purposes or whose nutritional value is not considered sufficient can be used as biojet candidates in the future. All of these can be used in aircraft either pure or as blended fuels. In addition, jet engines powered by 100% methyl ester will partially replace kerosene in the near future.

Acknowledgements

The authors acknowledge the financial support provided by Muson Makine Ltd. Şti.

Conflict of Interest Statement

The article author declares that there is no conflict of interest.

Author's Contributions

The authors declare that they have contributed equally to the article.

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