# Performance Assessment of Turbojet Engine Operated With Alternative Biodiesel

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# PERFORMANCE ASSESSMENT OF TURBOJET ENGINE OPERATED WITH ALTERNATIVE BIODIESEL

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## ABSTRACT

This study investigated experimentally the performance of turbojet engine fueled by biodiesel obtained from different feedstocks. The engine is equipped with measuring sensors for pressure, temperature, thrust, shaft speed in addition to flow meter, data acquisition system and a control unit. The results of the effect of biodiesel fuel type and its blends on turbojet engine performance are presented. Three biodiesel fuels which are Cotton methyl ester (CTME), Corn methyl ester (CRME) and Sunflower methyl ester (SME) and their blends of B10, B20 and B50 (10%, 20% and 50% biodiesel/Jet A1 by volume) are used and compared with the engine recommended fuel (Jet A1). Moreover, in this study, the Biodiesel fuel is produced through transesterification process in which the triglyceride (oil) reacts with alcohol (methanol) to form the mono-alkyl ester (biodiesel) and glycerol. Physical and chemical properties of all produced and tested fuels are measured. The results clearly indicate that the produced biodiesel fuels have a higher density, kinematic viscosity, than JetA-1 fuel, while, the calorific value of biodiesel fuels is very close to JetA-1 fuel. Moreover, JetA-1 fuel has higher sulfur content than other biodiesel fuels. Also, the experimental results show that Engine speed for the cases of using biodiesel fuels is lower than JetA-1 fuel at the same fuel throttle valve opening. Moreover, the Biodiesel fuels have a lower fuel volume flow rate compared to JetA-1 at the same throttle valve opening that lead to decrease the engine static thrust as well as lower value of TSFC.

## INTRODUCTION

Depletion of conventional fuel resources that provides most of the daily energy needs is the one of the major energy problems that has got great attention worldwide. In this line, there are many researches deal with development of technologies to use the natural renewable energy resources as efficient alternative fuels to the conventional one. It is well known that fuel driven transportation systems affect both economic growth and people movement worldwide, and consumes large portion of the world's petroleum originated fuels. For more worldwide economic growth, with considering the depletion of conventional petroleum fuels, more investigation of the effect of utilizing alternative fuels on engine performance need further investigation. However, the alternative fuels need to cover both the increase secure of the demand as well as reduce environmental impact footprint compared with conventional fuels. Also, alternative fuels must be technically feasible, economically competitive, environmentally acceptable and easily available. In this study, the engine used is turbojet similar to engines in service of aviation and military applications. This type of engine is a continuous combustion engine with steady flame combustion process. Throughout the literature, there are many investigation concerned with performance of various turbine engine types when they run by various types of biofuels. Moliere [1] cited that a wide variety of fuels could be used to provide clean combustion in gas turbine. The term biofuel is referred to any alternative fuels which are produced from biomass. Gupta et al. [2] reported that Straight Vegetable Oil, Biodiesel, Alcohols (Methanol and Ethanol), Biogas, Dimethyl Ether and Hydrogen are considered as biofuels for gas turbine engines. Also, they cited that biodiesel is a biodegradable, environmental friendly alternative liquid fuel for the diesel/aviation fuel and needs no engine modification. Demirbas [3] reported that the straight vegetable oils cannot be used directly in gas turbine due to its high viscosity. The advantages of biodiesel fuels are safe to use, to handle and to store as they has high flash point. This in case it compared with use of alcohol fuels as direct replacements to petrol or diesel, as the alcohol fuels introduces a significant hazard of an explosive mixture being present in the fuel tank due to their lower flash points. While, modification of combustor, fuel nozzle, burner and fuel tank are necessary to use Hydrogen and DME as a gas turbines fuel.

Instead of there are many researches have been carried out on studying the effect of biodiesel on diesel engine performance. There are few researches carried out to assess gas turbine engine performance when it's fueled by biodiesel. In the research line of use the biofuel for gas turbine, there are two types of gas turbines normal used: Industrial and aviation gas turbines. Most of the literature is related to utilization of biodiesel for gas turbines engines targeting mainly the industrial type used in power generation. While, limited research work in this literature deals with testing biodiesel as an alternative fuel for aviation gas turbines engine. Habib et al. [4] studied the performance of a 30 kW gas turbine engine using Jet A, blend of 100% (B100) and blend of 50% (B50) of Soy Methyl Ester (SME), Canola Methyl Ester (CME), Recycled Rapeseed Methyl Ester (RRME) fuels. They reported that the static thrust of pure biofuels was comparable to that of Jet A. This due to that the energy input to the engine was about the same while Thrust Specific Fuel Consumption (TSFC) for SME and CME B100 fuels is slightly lower at low engine speeds. In addition, TSFC of all B50 blends is not markedly different from the TSFC for the case of Jet A. Also, Habib et al. [4] reported that the thermal efficiencies for B100 SME, B100 CME, and B100 RRME biofuels are higher than Jet A as the presence of extra oxygen, which leads to leaner combustion and higher thermal efficiency. While, B50 blends of all fuels did not show significant differences from that the case of Jet A. In their study, the turbine inlet temperature when using B100 biofuels was slightly lower than that of Jet A at low speeds and approached that of Jet A at high speeds. Also, they cited that Exhaust Gas Temperature (EGT) was almost same for all used fuels. Nascimento et al. [5] investigated the thermal performance and emissions of a 30kW diesel micro-turbine engine at full and partial loads for steady state operating conditions. The engine was fed with diesel, castor biodiesel and their blends (diesel/castor) of 5%, 20%, 30%, 50%, 75% and 100% biodiesel. They reported that the difference in the micro-turbine heat rate was no higher than 10% at the same partial loads for the different blends and pure fuel, except when the power was lower than 5 kW. They also reported in the case of the micro-turbine operated with B100 there was a higher fuel consumption compared with other blends as well as the conventional diesel fuel case. In addition, for the case of low biodiesel concentrations, the fuel consumption remained the same as diesel fuel. However, at the case of the engine power reached the maximum value of 26kW with B100, the fuel consumption was 131 lit/hr, while, the fuel consumption was 111 lit/hr for diesel fuel. This is due to that the biodiesel fuel calorific value is lower than the calorific value of diesel fuel, therefore leads to this increase in biofuels fuel consumption. Rehman et al. [6] used a Jatropha oil blended with diesel fuel in a IS/ 60 Rovers gas turbine used for power generation. They reported that the Brake Specific Fuel Consumption (BSFC) for B15 and B25 is higher than that of diesel fuel, and, this is due to lower calorific value of the blends. Also, at lower engine loads the BSFC with biodiesel blends is higher but at medium engine load the BSFC of both B15 and B25 are lower than diesel fuel. This is due to the higher oxygen content of the biofuel blends that expected to enhance the combustion process. Rehman et al. [6] reported that the biodiesel contains ratio of 10-12% oxygen on weight basis which lowers its energy content and causes this reduction in both engine torque consequently the output power. Tan and Palanisamy [7] investigated through experiments and simulations the performance of 30kW micro turbine when fueled with waste cooking oil originated from palm oil source. They reported that the waste cooking biodiesel fuel resulted in higher fuel consumption due to that its calorific value is lesser compared with diesel fuel. They added that the biodiesel fuel leads to a higher thermal and combustion efficiency due to the presence of oxygen that leads to complete combustion process. Krishna [8] reported that the efficiency of the turbine has no change when it was tested at different ambient condition for all cases of biodiesel blends and conventional fuels. Purssi et al. [9] tested the effect of blends from 10% up to 30% volume of Straight Vegetable Oil (SVO) on volume of diesel fuel on the output power of micro gas turbine (MGT). They reported that during all test runs with SVO the measured maximum power was the same for diesel fuel case. Moreover, the biofuel consumption was increased with 5% in volume, to balance the difference between the Lower Calorific Value of the two fuels.

In addition, the fuel pressure during operation with SVO was increased by about 30%. Nascimento et al. [10] used 30 kW regenerative diesel micro gas turbine engine in order to compare its performance when it run with pure biodiesel that obtained from different sources, which were castor, soybean, and palm oil. They reported that, the output engine power in case of biodiesel is slightly lower than its output power when run with diesel fuel by about 4.26%. Moreover, the castor biodiesel fuel shows the highest SFC, being followed by soybean and palm oil respectively. Zabihian et al. [11] developed a steady-state model to evaluate the performance of a 100 kW micro-gas turbine used for power generation with the blends of 10%, 20%, and 30% of biodiesel and petro-diesel. They compared the model output results with their correspondence experimental one. Their results showed that the model predictions changed with the fuel type. Also, the fuel volumetric flow rate is increased with the increase of the percentage of biodiesel in the blend. Chiang et al. [12] tested the performance of a 150kW micro turbine used for power generation by using different blend ratio with biodiesel of 10%, 20% and 30 % respectively. They reported that, the fuel consumption rates increase as the biodiesel percentage increase in fuel due to the lower calorific value of the biodiesel fuel compared with diesel fuel. Also, the thermal efficiencies for the three tested cases remain unchanged. Nascimento and Santos [13] presented overview for experiments carried out by 7 researchers during 11 years (1995-2006). The 7 researchers utilized biodiesel to drive gas turbine engines mostly used for power generation. They used in their experimental investigation the following biodiesel: Soybean, Rapeseed, Sunflower, Animal fat and castor in blends ranged from 5% to 50%. They concluded that the SFC and thermal efficiency of the engines increase with increasing the biodiesel blend. Also, the SFC for biodiesel is higher than diesel because the heating value of biodiesel is lower than that of the diesel fuel. Moreover, the thermal efficiency of biodiesel is higher than diesel fuel due to the oxygen content in biodiesel which leads to complete combustion process.

For biodiesel production process, Saleh [14] produced cotton methyl ester (CME), cotton ethyl ester (CEE) and CEE–diesel blends from cottonseed oil (CSO). This was a part of his experimental work investigating the optimum conditions for biodiesel production process. Saleh [14] cited that the optimum parameters for biodiesel production process were oil/alcohol molar ratio is 1:6, the amount of lye is 1% by the weight of the oil and the reaction time is about 75 min. Also he reported that 89% of the neat CSO was converted into CME or CEE, and, the use of different alcohols (methanol or ethanol) presents few differences the output biofuel are almost same. Demirbas [15] reported that the free fatty acids and water are the main factors that affecting the quality of conversion the oil to biodiesel through transestrification process. This is due to the presence of both free fatty acids and water consumes catalyst in addition they causes soap formation and reduces the conversion of oil to ester. Demirbas [15] investigated the parameters that affects the transesterification process which are molar ratio of alcohol to oil, alcohol type, amount of catalyst, reaction temperature, pressure, and reaction time to determine the best conditions to perform the reaction. He observed that the increase in the reaction temperature has a great influence on the yield of ester conversion. Moreover, the yield of alkyl ester increased with increasing the molar ratio of oil to alcohol. Usta [16] observed that as the reaction time is longer is lead to better the conversion percentage. Moreover, the rate of transesterification is rises with the increase of reaction temperature. However, the maximum operating temperature cannot exceed the boiling point of the alcohol used in the transesterification process.

For the available literature, it is clear that experimental assessment of gas turbine engine performance when fueled by biodiesel blends has been widely covered. While, experimental assessment of turbojet engine when it fueled with biofuel blends is limited cases. Therefore, this study aims to assess the condition that leads to the highest turbojet engine performance and efficient operation when fueled with biodiesel fuels. Three different types of biodiesel fuels namely Cotton Methyl Ester (CTME), Corn Methyl Ester (CRME) and Sunflower Methyl Ester (SME) and their blends of B10, B20 and B50 (10%, 20% and 50% biodiesel/Jet A-1 by volume) are produced, characterized and tested to assess experimentally the turbojet engine performance when fueled with these biofuels.

## EXPERIMENTAL PROCEDURE AND MEASUREMENTS

### Biodiesel Fuel Production

Production of biodiesel targeting to reduce the high viscosity of the vegetable oils in order to enable their use in combustion engines without any operational difficulties. As cited in the literature, biodiesel is commonly produced in transesterification process. This process is a chemical process of transforming large branched triglyceride molecules of vegetable oils and fats into smaller straight chain molecules which is almost similar in size to the molecules of the species present in diesel fuel. A catalyst is usually used to improve the reaction rate.

In this study, the transesterification process is performed using a controlled hotplate heater with a magnetic stirrer, two beakers one of 2000 ml volume and the other of 250 ml, sensitive scale up to 10-4g and a 50 ml volume pipette. The process is summarized as following:

1- Oil is filtered to remove solid particles, in some cases this process may be cancelled if pure oil is used. However, to filter the oil, it should be warmed up to 35$^o$C, and then either the oil is left to run freely by using a double layer of cheesecloth in a funnel or use any other filtering method.

2- Water contents are to be removed from the waste oil as it affects the reaction rate and cause soap formation. Water is removed from oil by raise the water temperature to the boiling temperature (100$^{o}$ C) therefore water vapor goes out the oil.

3- Determine the amount of lye to be used. It should more accurate and it is estimated as 5.5 grams of Lye NaOH for every one liters of vegetable Oil.

4- Preparing the catalysts which in this study its sodium methoxide. Sodium methoxide is prepared carefully by treating methanol with sodium as follow.

$$NaOH + CH_3OH \rightarrow CH_3ONa + H_2O$$

5- The amount of methanol used in the previous step is about 20 - 25 % of the oil by volume. Lye and Methanol are being mixed together until the lye completely dissolved in the methanol to avoid formation of soap.

6- The Oil is heated to the temperature from 100 to 120$^{o}$ C, followed by taking the container away from the heater then performing the mixing process. During mixing process sodium methoxide is added as droplets and stirred with the mixture for period of 10 to 15 min. Thereafter, the mix is left to cool and separation process. The transesterification reaction is as follow.

| Vegetable oil | Methanol | | Biodiesel (FAME) | | Glycerin |
|---|---|---|---|---|---|
| CH2-OCOR1 | | | R1COOCH3 | | CH2-OH |
| CH-OCOR2 | + 3 CH3OH | Catalyst ⟷ | R2COOCH3 | + | CH-OH |
| CH2-OCOR3 | | | R3COOCH3 | | CH2-OH |
| | | | Mono-Alkyl esters | | |

7- The separation process is carried out after the mixture is left for a couple of hours, and, the biodiesel is float on top of the mixture produces in step number 6. While, the denser glycerin is congealed on the bottom of the container forming a hard gelatinous mass as can be see from figure 1. In this stage, the biodiesel can be separated easily by draining it out of the container.

8- To ensure removal of any glycerin and soap contents from the produced biodiesel, washing of biodiesel is carried out with water and the biodiesel is separated again through drain it out of the beaker.

9- In order to guarantee the washed biodiesel is free of water content, as the step number 2.

In this study, biodiesel fuels are produced from cotton, corn and sunflower oils. After, biodiesel fuels are produces and its blends with Jet A-1, they are tested at different turbojet engine throttling opening percentage from full open case.

**Fuel Properties**

Physical and chemical properties of biodiesel fuels and JetA-1 used in this study are measured according to ASTM D6751 in addition to ASTM D97 and ASTM D240 Standards. The measured data values for all the biodiesel fuel properties and JetA-1 are shown in Table1. The measured data are the density, kinematic viscosity, pour point, flash point, sulfur content, higher and lower calorific value and hydrogen and carbon contents. From table1, it can be seen that the kinematic viscosity for biodiesel fuels is higher than JetA-1fuel. However, blending biodiesel fuels with JetA-1 leads to reduce the viscosity, consequently, it can be used to fuel the turbojet engine without operational problem. Throughout the fuel properties measurements it is clearly found that the sunflower biodiesel contains water in its composition therefore, it has a very high viscosity and density compared to corn and cotton biodiesel fuels. Also, its clearly seen that the flash point of biodiesel fuels is higher than JetA-1.This leads to that fact that the produced biodiesel fuels is save in storage compared with JetA-1 fuel. In addition, Jet A-1 has a higher sulfur contents compared with biodiesel fuel, while, its calorific value is higher compared with other biodiesel fuels.

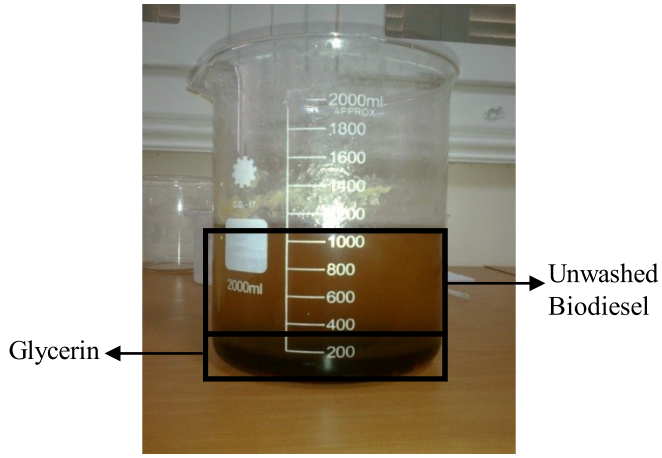


**FIGURE 1. SETTLING PROCESS**

**Experimental Setup**

A small turbojet engine that can generates up to 230 N of thrust, manufactured by AMT Netherlands, is used in this study to investigate the different type of biodiesel fuels on its performance. The turbojet engine is a single spool turbojet engine, and, it has a single-stage centrifugal compressor, unique stage axial flow turbine and a fixed convergent nozzle. The combustor chamber is of annular type. The engine is designed with stainless steel inlet duct that allows the inlet air flow rate to be measured. The engine is supplied with control unit to control the position of the fuel throttling valve which consequently controls the engine rotational speed. Also, the control unit limits the exhaust gas temperature to 750$^{o}$C [17]. The basic of this turbojet engine specifications are shown in Table 2. This engine can runs on liquid fuel, either kerosene or Jet A-1.

TABLE 1. PHYSICAL AND CHEMICAL PROPERTIES OF PURE BIODIESEL FUELS AND JET A-1

| Properties | Method | CTME | SME | CRME | JetA-1 |
|---|---|---|---|---|---|
| Density at 15.5°C | ASTM D-1298 | 0.8938 | 1.0188 | 0.8924 | 0.797 |
| Kinematic Viscosity, cSt, at 40°C | ASTM D-445 | 7.34 | 14.37 | 6.92 | 1.08 |
| Pour Point °C | ASTM D-97 | -3 | -6 | -12 | -43 |
| Flash Point °C | ASTM D-93 | 175 | N.D | 173 | 39 |
| Sulfur Content, ppm | ASTM D-4294 | 15.2 | 9.4 | 10.2 | 50.3 |
| Higher Calorific Value (kJ/kg) | ASTM D-240 | 44649 | 44624 | 44914 | 46329 |
| Lower Calorific Value (KJ/kg) | ASTM D-240 | 42189 | 42564 | 42376 | 43465 |
| Hydrogen Content (%mass) | | 11.58 | 9.7 | 11.6 | 13.48 |
| Carbon content (% mass) | | 88.42 | 90.3 | 88.4 | 86.51 |

TABLE 2. OLYMPUS HP TURBOJET ENGINE [18]

| | |
|---|---|
| Engine Type | Turbojet |
| Engine Name | Olympus E-start HP gas turbine |
| Diameter | 131 mm |
| Length | 384 mm |
| Turbine weight | 2850 g |
| Compressor | Single stage radial compressor |
| Combustion Chamber | Annular combustion chamber |
| Turbine | Single stage axial flow turbine. |
| Pressure ratio at max. rpm | 3.8 :1 |
| Maximum RPM | 108,500 rpm |
| Thrust at max. RPM | 230 N |
| Thrust at min. RPM | 13 N |
| Mass flow at max. rpm | 450 g/sec |
| Fuel consumption at max. rpm | 640 g/min |
| Normal EGT | 700 °C |
| Max. EGT | 750 °C |

It needs no separate lubricating oil reservoir as the bearings are lubricated by a small percentage estimated about 4.5% of Mobil jet oil II or Areoshell 500 that mixed with the fuel. The engine equipped with 5 liters fuel tank with a metal fuel filter located inside the fuel tank. Propane canister is used in the engine start up in order to make engines reaches its operating temperature rapidly. The engine is equipped with five k-type thermocouples, and pressure sensors manufacture by Honeywell with measuring range from 0 to15 psi temperature and pressure measurements at the compressor inlet, compressor exit, turbine inlet and exit and thrust nozzle exit. Pitot tubes were employed to measure the stagnation pressure. A low flow rate turbine meter with range from 0.1 to 2.5 liter/min is used to measure the fuels flow rate. The flow meter reading is applicable to measure the flow rate of biodiesel, as the flow meter can measure fluids with viscosity up to 15 cSt. A 0-20 kg range thrust cell equipped with the engine is used to measure static thrust. Armfield shaft speed sensor with measuring range up to 130,000 rpm is used to measure the engine rotational speed. The speed sensor is also used by the engine Control Unit to govern the engine to a maximum speed of about 108,000 rpm in normal operation, as there is no mechanical governor fitted to this turbojet engine. The air mass flow rate is determined from the differential pressure sensor fitted to the inlet orifice. The schematic diagram shown at figure 2 indicates the layout of the engine, connection between sensors, electric console and user computer. The measuring sensors and devices allow to measure and determine the specific thrust, thrust-specific fuel consumption (TSFC), engine thermal efficiency, exhausts gas speed and intake air speed. As it can be expected, engine start by use biofuels might lead to the effect of the fuel pump and injectors in the engine, therefore, a fuel manifold is added to the gas turbine fuel delivery system that

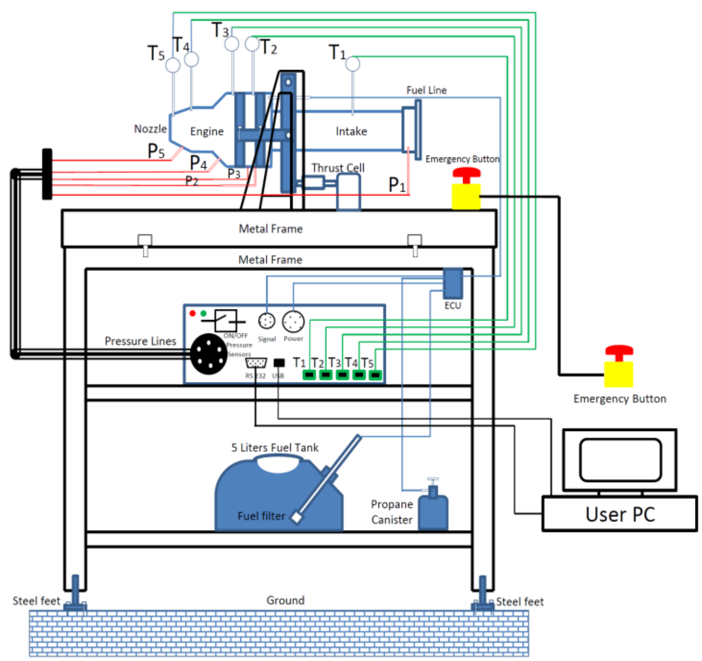


FIGURE 2. LAYOUT OF THE CONNECTIONS BETWEEN SENSORS, ENGINE, ELECTRONIC CONSOLE AND USER PC.

allow the engine to start with Jet A-1, then, switched to the biofuel test experiment, followed by run with Jet A-1 to purge the biofuel from the system.

**Experimental Procedure**

The experimental test procedure adapted in the present work is as follows:

1- Preparation of the tested fuels which are CTME, CRME and SME and their blends of B10, B20 and B50 with Jet A-1.
2- The fuel is premixed with 4.5 % of its volume with turbine oil (Mobil Jet Oil II) before it can be used. This is due to that the turbine uses the oil mixed with fuel for lubrication.
3- Check and connect the propane canister. As pre-requirement for engine start-up, propane gas is used to initiate its combustion and operation.
4- Adjustment of the measuring instruments to zero reading.
5- Startup sequence is initiated and the engine is controlled at throttle valve of the fuel setting of 0% which corresponds to a fuel volume flow value of about 0.17 lit/min that keep the engine running at about 37000 RPM.
6- Varying the fuel throttling valve at different opening values ranged from 0% to 95% with step of 10 %, in which at each opening percentage value, the data required to determine the engine performance is measured and recorded.
7- Before each experiment with alternative fuel, the engine operate with jet A-1 fuel in order to make sure that the engine fuel system is clean of any residuals from the previous biodiesel tested fuel.

Comparison between effects of each alternative biofuel on the engine performance is held between Jet A-1 and other biodiesel blends. The obtained results are shown in next section.

## RESULTS AND DISCUSSION

**Performance Assessment of Turbojet Engine**

Experimental measurements are carried out to assess the performance parameters of turbojet engine when it's fueled with maker recommended fuel (JetA-1) and blends of JetA-1 fuel with CTME, CRME and SME biofuels. For each experiment runs with alternative fuel, the engine performance reference parameters were obtained by using 100% JetA-1 as a baseline. This is done in order to compare the performance parameters with those obtained when the engine runs with different biodiesel fuels at different blends. In the results discussion, performance parameter is discussed in case of the fuel throttle valve position is 30% and 80% these are correspondence to low and normal operating conditions of the engine.

**Effect on Engine Speed and Fuel Volume Flow Rate**

The results of experimental investigation on effect of different biofuel blends on engine speed at different opening of the fuel throttle valve compared with JetA-1 are shown in figure 3. The experiment is carried out at different blends of SME, CTME and CRME of B10, B20 and B50 respectively. As shown in figure 3, the engine speed increases as fuel throttle valve opening increase as more fuel is injected into the combustor for all tested fuels. From the results shown in figure 3 and for the same throttle position, the engine speed is higher when the engine fueled by JetA-1 compared with all tested biodiesel fuels and their blends. At fuel throttle valve opening of 30%, the results clearly show that the effect the biofuels fuel blends of 10, 20 and 50% lead to variation in the engine speed is ranged from -2.36% to 0.3% compared with JetA-1 fuel. While for the case when the fuel throttle valve opening is 80% the variation in the engine speed is ranged from -1.78% to 0.12%. The effect of fuel throttle valve opening percentage on the fuel volume flow rate is shown in figure 4. The results shown in the figure is for biofuel blends ratio of 10, 20 and 50% at 30% throttle valve opening it can be seen the the fuel volume flow rate is decreased by ratio ranged from 3.8% to 17.46%. While for the case of throttle opening 80%, the fuel volume flow rate is decreased by ratios ranged from 5.21% to 17.36%. From the data presented in figures 3 and 4, it is clear that for the same fuel throttle valve position the volume flow rate of biodiesel fuels and its different blends is lower compared with JetA-1 fuel. Also, for SME, CTME and CRME fuels blends, the results show that as the blend of biodiesel increases, the fuel volume flow rate is decreased; consequently, the engine speed is decreased. These results are attributed to the higher viscosity of biodiesel fuels (see table 1). Also, from the results clearly show that the engine speed is low for the case of CRME fuel followed by CTME and the lowest engine speed is achieved with SME and its blends compared with the case of JetA-1 fuel. This is due to that SME fuel and its blends have the highest kinematic viscosity among all other biofuels (see table 1). The higher the biofuel viscosity leads to decrease the engine fuel gear pump outlet pressure, consequently, the fuel mass flow rate. As the fuel mass flow rate decreased, the engine output power is decreased and is reflected on the measured turbojet engine speed by 2.43%. However, it can be concluded the turbojet engine speed is slightly affected inversely when fueled with SME, CTME and CRME biofuels and their blends due to their higher viscosity.

**Effect on Engine Static Thrust**

The results investigating the effect of different biofuel blends on engine static thrust at different fuel mass flow rate compared with JetA-1 fuel are shown in figure 5. The experiments are carried out at different blends of SME, CTME and CRME of B10, B20 and B50 biofuels. As shown in figure 5, for the JetA-1 fuel, as the throttle valve opening is changed from 20% to 95%, the fuel mass flow rate is increased from 3.34 g/sec to 11.43g/sec and the engine speed increased from 61,000 rpm to 105,000 rpm as expected due to the increase of the fuel mass flow rate. In addition, the engine static thrust is increased

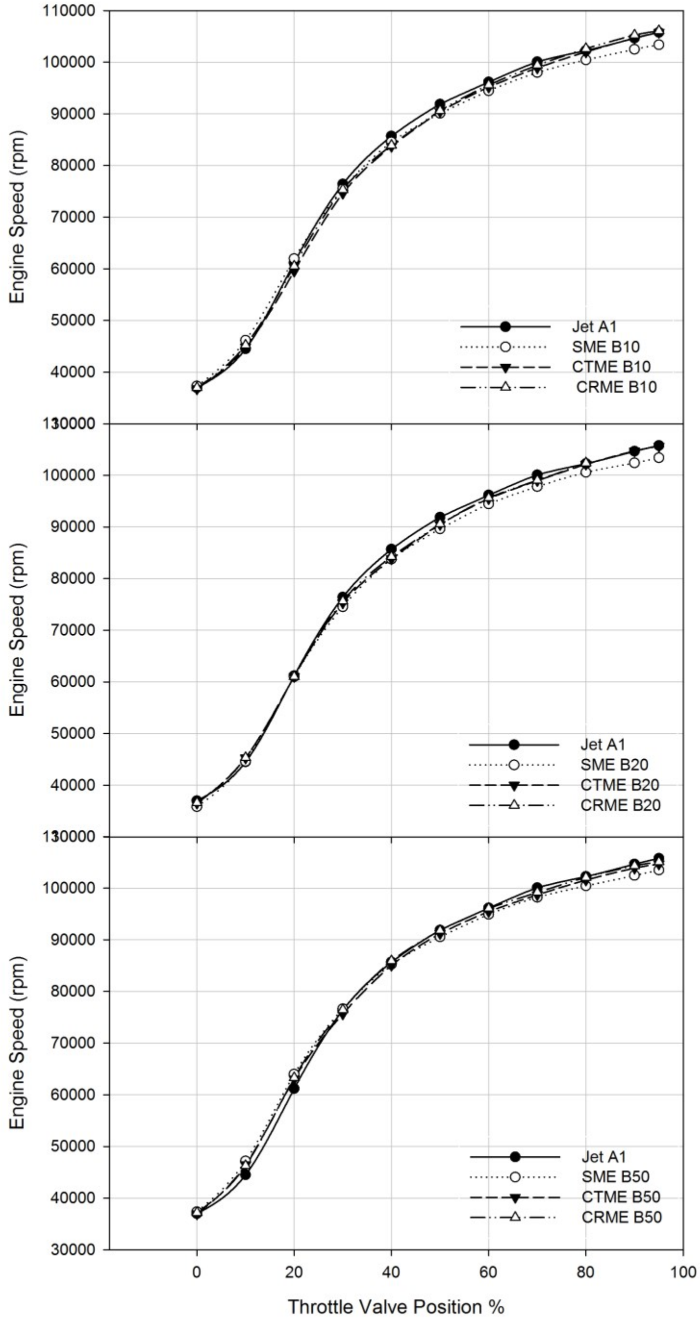


**FIGURE.3 EFFECT OF DIFFERENT BIOFUEL BLENDS ON ENGINE SPEED AT DIFFERENT THROTTLE VALVE OPENING COMPARED WITH JETA-1 (A) B10 (B) B20 AND (C) B50.**

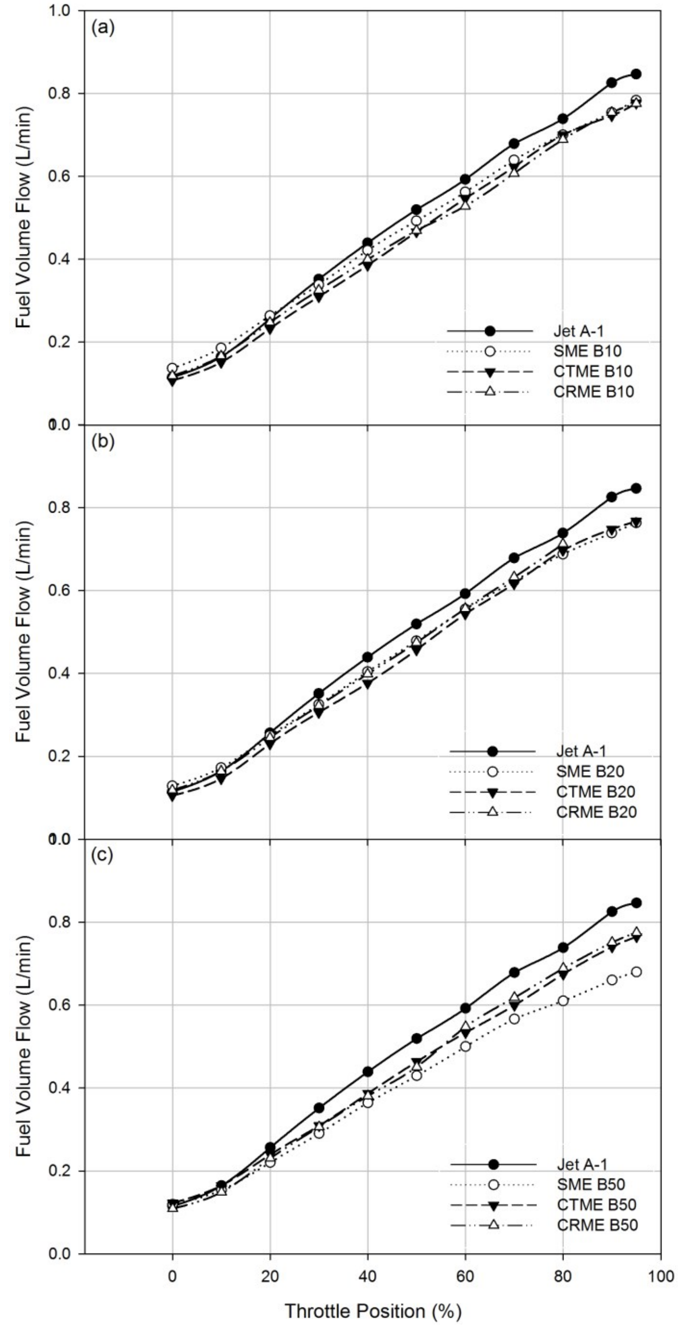


**FIGURE.4 EFFECT OF DIFFERENT BIOFUEL BLENDS ON FUEL VOLUME FLOW RATE AT DIFFERENT THROTTLE VALVE OPENING COMPARED WITH JETA-1 (A) B10 (B) B20 AND (C) B50.**

from 35 N to 182 N. The measurement of the engine static thrust when the engine runs at different fuel mass flow rate with biofuel blends ratio of 10, 20 and 50% at throttle opening of 30% is shown in figure 5. The results show that, the engine static thrust is decreased by ratio ranged from 1.79% to 7.57%. While for the case of the fuel throttle valve opening is 80% the engine static thrust is decreased ranged from 3.36% to 8.96%. The decrease in the measured static thrust of the engine for the case when the engine fueled with biodiesel fuel is due to the decrease in the engine output power as a result of lower fuel mass flow rate of the biodiesel fuels at this throttle valve opening compared with Jet A-1 fuel. The results of effect of different biodiesel fuels on the engine static thrust at the same value of fuel mass flow rate show that when the engine is fueled with CTME biofuel it has the higher static thrust compared with SME, CRME biofuel and JetA-1fuel. This result was obtained at the blends of 10% and 20%, respectively. For SME biofuel at blend of 50% and same fuel mass flow rate, the engine produces the highest value of static thrust compared with other fuels. While for SME B20 biofuel the engine static thrust is lower by about 11.2 % than the correspondence value of JetA-1 at throttle position of 90%. As the SME biofuel has the higher viscosity among the other biofuels, it show no fixed trend on the engine static thrust at different blend as a function of the fuel throttling valve opening (fuel mass flow rate).

**Effect on Thrust Specific Fuel Consumption**

Figure 6 shows the effect of different biofuel blends on engine thrust specific fuel consumption at different fuel mass flow rates compared with JetA-1fuel. The Experiment is carried out with SME, CTME and CRM biofuels with blends of B10, B20 and B50 respectively. The Thrust specific fuel consumption (TSFC) is defined as the mass of fuel that required providing the net thrust for a given period. The measurements show that low engine speeds are obtained when the throttle valve position is at less than 40% of the full opening. The difference between TSFC value of JetA-1 compared with the cases of biodiesel fuels at different fuel mass flow rate is slightly higher. This difference is gradually decreases with the increase of throttle valve opening, and it is found that at throttle position of 40% or higher that the difference between the value of TSFC of JetA-1 and the biodiesel fuels become smaller. However, the lower value of TSFC for biodiesel fuels and blends compared with the case of JetA-1 for experiment runs shown in figure 6 are in agreement with similar results presented in Habib et al. [4]. Also, Figure 6 shows that, as the blend of biofuel increase, the value of TSFC get decrease. This due to that, the viscosity and density of the fuel are increase with the increase of blend of the biofuel (see table 1). Therefore, it can be concluded that the decrease in the value of TSFC is attributed to the increase in both fuel viscosity and density. On the contrary, it was expected that the TSFC of biofuels will be higher than that of JetA-1 fuel as the calorific value of biofuels is lower than JetA-1 (see table 1). Based on the fact that for same power as the calorific value of the fuel decreases, the fuel consumption will increase. However, the obtained result reveals that the fuel consumption of biofuels is lower than that of JetA-1 which means that the effect of fuel both density and viscosity of fuels overcomes the effect of the calorific value and leads to increase in fuel consumption.

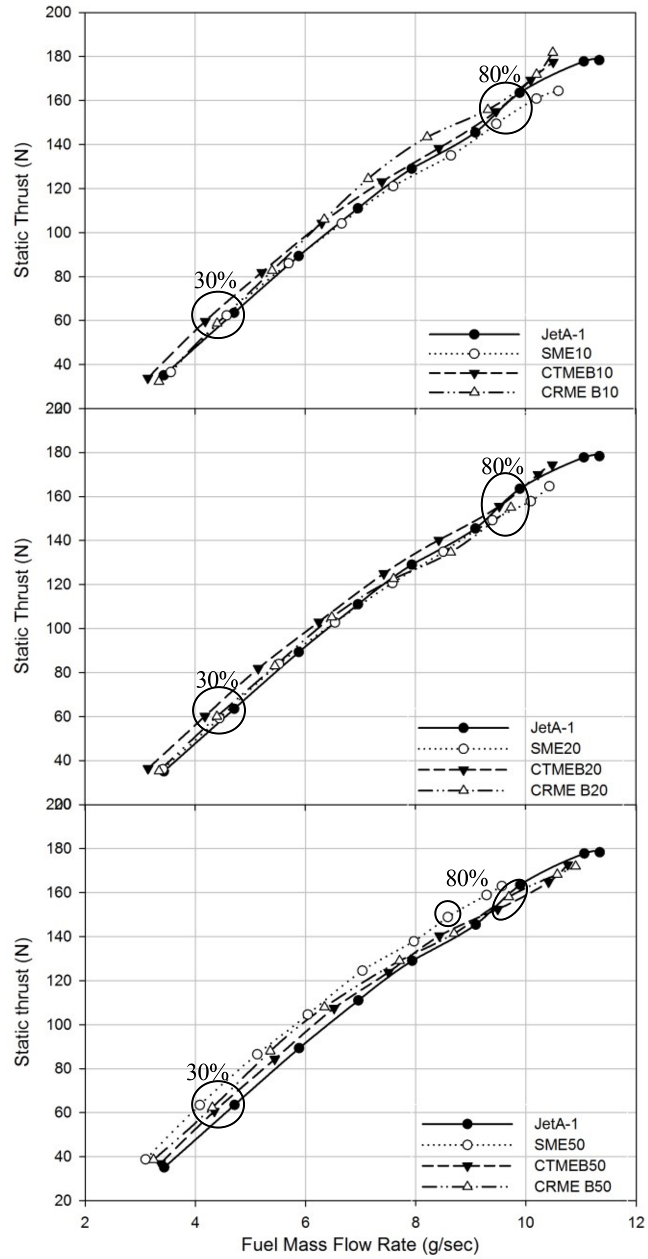


**FIGURE.5 EFFECT OF DIFFERENT BIOFUEL BLENDS ON STATIC THRUST AT DIFFERENT FUEL MASS FLOW RATES COMPARED WITH JETA-1 (A) B10 (B) B20 AND (C) B50.**

## CONCLUSIONS

This study investigated experimentally the performance of turbojet engine fueled by biodiesel obtained from different feedstocks. Three biodiesel fuels which are Cotton methyl ester (CTME), Corn methyl ester (CRME) and Sunflower methyl ester (SME) and their blends of B10, B20 and B50 (10%, 20%

 

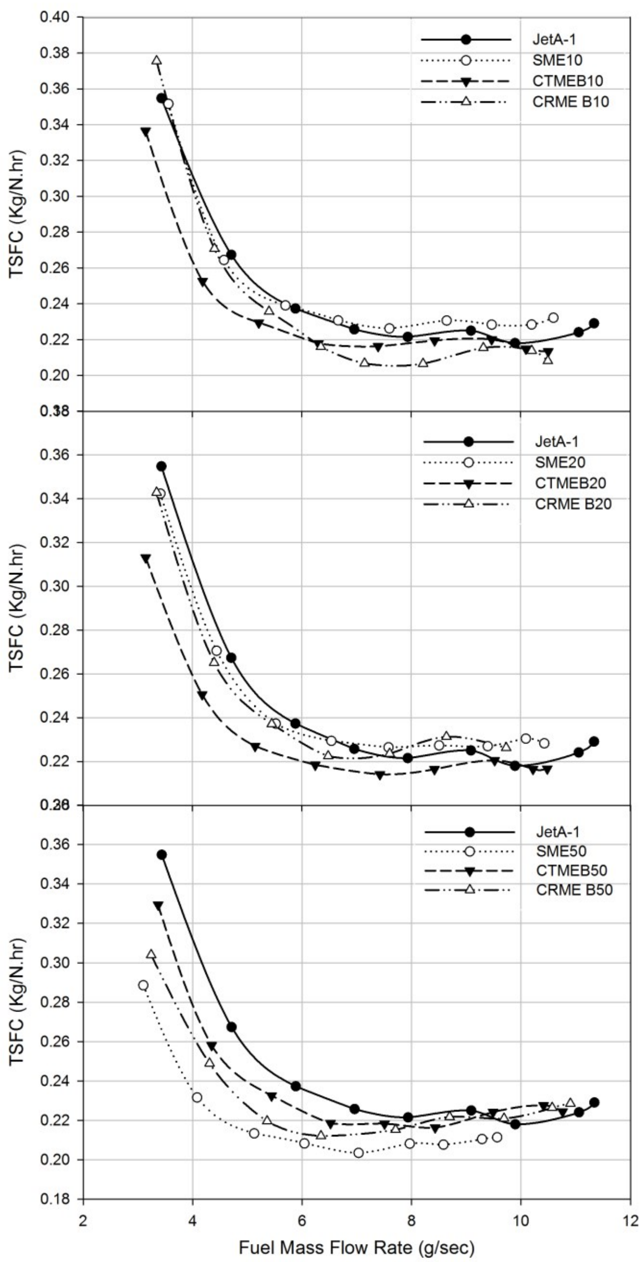


**FIGURE.6 EFFECT OF DIFFERENT BIOFUEL BLENDS ON TSFC AT DIFFERENT FUEL MASS FLOW RATES COMPARED WITH JETA-1(A) B10 (B) B20 AND (C) B50.**

and 50% biodiesel/Jet A1 by volume) are used and compared with the engine recommended fuel (Jet A1). Moreover, the Biodiesel fuel is produced through transesterification process in which the triglyceride (oil) reacts with alcohol (methanol) to form the mono-alkyl ester (biodiesel) and glycerol. Physical and chemical properties of all produced and tested fuels are measured.

Based on the performed experimental work, the results can be concluded as following:

- Biodiesel fuels have a higher density, kinematic viscosity, flash point and pour point than JetA-1 fuel, while, their calorific value, carbon and hydrogen contents is very close to JetA-1 fuel. However, the JetA-1 fuel has higher sulfur content than other biodiesel fuels.
- Blending biodiesel with JetA-1 can be a suggestion to overcome the problem of the higher viscosity of the pure biodiesel fuels.
- Experimental results show that at the same fuel throttle valve opening, the highest engine speed achieved by JetA-1 fuel when it compared with other biodiesel fuels. SME biofuel and its blends have the lowest engine speed due to that it has the highest viscosity.
- Biodiesel fuels volume flow rate is decreased by ratio ranged between 3.8% and 17.46% for the case of 30% opening of the fuel throttle valve, while it is ranged between 5.21% and 17.36% for the case of 80% throttle valve opening. Also, at the same throttle valve opening, the biodiesel fuels and their blends have a lower volume flow rate compared with JetA-1.
- The higher the biofuel viscosity leads to decrease the engine fuel gear pump outlet pressure, consequently, the fuel mass flow rate. As the fuel mass flow rate decreased, the engine output power is decreased and this is reflect on the turbojet engine speed reduction by 2.43%.
- At the same throttle position, JetA-1 fuel has higher static thrust than biofuels that due to that the biodiesel fuels at the same throttle valve position have a lower fuel mass flow rate compared to JetA-1 fuel.
- TSFC for the case of biofuels is lower than the case of Jet A-1. This is attributed to the increase in both fuel viscosity and density. This result reveals that the fuel consumption of biofuels is lower than that of JetA-1 which means that the effect of fuel both density and viscosity of fuels overcomes the effect of the calorific value and leads to increase in fuel consumption.

Nomenclature

| | |
|---|---|
| A/F | Air to Fuel Ratio |
| ASTM | American Standard of Testing and Materials |
| BSFC | Brake Specific Fuel Consumption |
| B | Blend of biodiesel with JetA-1 |
| CEE | Cotton Ethyl Ester |
| CET | Combustor Exit Temperature |
| CME | Canola Methyl Ester |
| CRME | Corn Methyl Ester |
| CSO | Cotton Seed Oil |
| CTME | Cotton Methyl Ester |
| EGT | Exhaust Gas Temperature |
| FAME | Fatty Acid Methyl Ester |

MGT Micro Gas turbine
RRME Recycled Rapeseed Methyl Ester
SME Sunflower Methyl Ester
SVO Straight Vegetable Oil
TSFC Thrust Specific Fuel Consumption

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