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# Emissions Characteristics of Biofuel in Micro Gas Turbine Engine

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*Abstract*— **various studies have shown that there is increasing interest in the use of biofuels in aviation sector. This work was aimed at providing an approach for a low cost, portable and reasonably accurate method for testing for biofuels with the use of a micro gas turbine engine. The pollutants and hydrocarbon evolution of the exhaust gases were analyzed. Jet A1 and blends of Jet A1 and biodiesel in volume ratio 90:10 (B10), 80:20 (B20), 70:30 (B30), 50:50 (B50) and 30:70 (B70) mixed with 2.5% turbine lubricating oil were tested. The fuels were tested at three load conditions (throttle settings): Full power, 70% and idle condition. CO, $CO_2$, NOx, hydrocarbons where detected via Fourier Transform Infra-red Spectroscopy (FT-IR) in the entire effluent streams. The results showed that higher blends of biodiesel emitted higher concentration of some of the pollutants than Jet A1. High emission from higher blends of biodiesel was thought to be as a result of poor atomization, vaporization and mixing which becomes more difficult with higher concentration of biodiesel in the blends.**

Keywords— ***Biodiesel, Micro Gas Turbine Engine, Fourier Transform Infra-red Spectroscopy (FT-IR), waste cooking oil, pollutants***

## I. Introduction

Atmospheric $CO_2$ has been reported to be on a rapid increase in recent times mainly due to the rising consumption of fossil fuel for anthropogenic activities. Therefore, the reducing consumption of fossil fuels in the bid to reduce $CO_2$ emissions has more or less become an object of research obsession in the race to achieve the reduction of global warming [1, 2]. Also of concern are the effects of atmospheric pollution resulting from toxic emissions released when some fossil fuels are combusted. Normal combustion process of fossil fuel usually results to the release of particulates, carbon dioxide, hydrocarbons methane, nitrogen oxides and other emissions into the atmosphere.

Currently about 25% fossil fuels are consumed by the transportation sector and aviation sector consumes about 13% of transport fuel consumption, which is the second biggest sector after road transportation. About 15,750 aircraft in commercial aviation operate on fuel derived from fossil fuels, contributing about 2-3% of global carbon emissions[3].The need to find an alternative cost-effectively friendly fuel becomes imperative when global warming and increasing petroleum costs due to diminishing oil, gas and coal reserves are considered [1,4,5]. Also, decreasing improvement of fuel efficiency, increasing requests for cleaner/greener air transportation coupled with growing political and public pressures targeting air transportation to reducing its greenhouse gas emissions, rapid growth of aviation sector. Environmental impact and the future security of supply of fuels have led to increased interest in potential use of alternative fuels in aviation gas turbines. [3,6,7]. Aviation presents more restrictions on candidate fuel unlike other sectors due to various factors like safe and reliable conditions of combustion, ability of the proposed product to be fully compatible with the current jet fuel in order to prevent varying qualities and commercial limitations and also its suitability in the current engine technology [7]. This has led to the development of an alternative aviation fuel. Alternative aviation fuels are renewable fuels which can be blended with petroleum products and can be can effortlessly introduced without the need to change its fuelling system, turbine design, storage facilities and infrastructure[8,9].

The aim of this paper is to determine of gaseous emissions of Jet A1 and various biodiesel blends using a micro gas turbine engine.

## II. MATERIALS AND METHODS

The research was carried out on an affordable scaled down version of a turbo jet (MW54 Mk3), it comprises of centrifugal compressor, combustion chamber, and a converged exhaust cone. Fuel was injected into the vaporizer tube which directs the fuel vapor to the combustion chamber where it is mixed with air.

The fuel that was used to power the micro gas turbine engine in this research was a biodiesel derived from waste cooking oil from food industry which has been converted into high quality biodiesel. Jet A1 and blends of Jet A1 and biodiesel in volume ratio 90:10 (B10), 80:20 (B20), 70:30 (B30), 50:50 (B50) and 30:70 (B70) mixed with 2.5% turbine lubricating oil were tested. **Jet A-1:** This is a kerosene type of fuel suitable for most turbine engine aircraft produced to international standard. Its flash point is above 38 0C and a freeze point of -47 $^{0}$C. The fuels were tested at three load conditions (throttle settings): Full power, 70% and idle condition. At maximum thrust, the engine consumed 210 ml of fuel in a minute and 50 ml of fuel at idle position.

The engine was mounted on a stand fixed to the test bench which has a slider platform. The engine thrust was measured using a potentiometer; this was as a result of a pressure transducer that was mounted on the stand to measure the resistance change. A thermocouple placed through an opening in the exhaust cone protruding at about 2mm into the exhaust steam was used to measure the exhaust gas temperature. The FADEC which is a control system for the engine was used to regulate and control fuel pump, measure rpm, throttle positions and exhaust gas temperatures and also for operating the devices used for starting the engine. In this research, A Gasmet CR-2000 FT-IR was used for detecting and quantifying the emissions. This model was designed for laboratory research applications which includes catalyst research applications, motor exhaust measurements, or to measurement of compounds in wet corrosive gas mixtures [10]. Calibration of Gasmet FT-IR was made by the manufacturer. Exhaust gases from the exhaust cone was channeled into a 20 cm diameter duct, where the exhaust gases was diluted by the ambient air. Samples from the exhaust were taken by dipping one end of a one meter long stainless steel tube into the exhaust cone. This was later taken through a two meter heated sample line connected to the FT-IR. The exhaust sample and the filter sample were extracted using a sampling handling unit at a constant rate between 2 to 3 mints before introducing it into the FT-IR. The temperature remained constant at 196 ± 20°C all through the handling process. The gases were measured on the criteria of wet basis. The Gasmet FT-IR technical specifications could measure emissions between the ranges 0.5- 3ppm depending on the application. Zero operation was done before the measurement in order to prevent error in measurements. For the purpose of this research, the instrument was pre-calibrated for 54 regulated and non-regulated pollutants. At a sample flow rate of between 2 to 3 mints, the sample rate of FT-IR is also 2 sec. The regulated pollutants discussed here are CO, $CO_2$, NOx, $SO_2$ and THC.

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## III. RESULTS AND DISCUSSION

The $CO_2$ emission as a function of throttle settings for Jet A1 and biodiesel blends tested in the micro gas turbine engine is presented in Figure.1. It can be seen B50 has the lowest percentage of $CO_2$ emission of about 0.9%. The results showed that the emissions increases in each fuel as the throttle position increases. B20 and B30 had the same rate of $CO_2$ emission of 0.95% at full power. Jet A1 had an emission of about 1.15% at full power. Although B70 had the highest $CO_2$ emission at all throttle settings which could be as a result effect from land use, production method or the feedstock used. The energy and carbon released when biodiesel burns as fuel could be the $CO_2$ absorbed from the atmosphere by the plant feedstock used. The emission of $CO_2$ at idle position of B70 (1.34%) is seen higher than the emission at B10 at full power which is 1.28%.

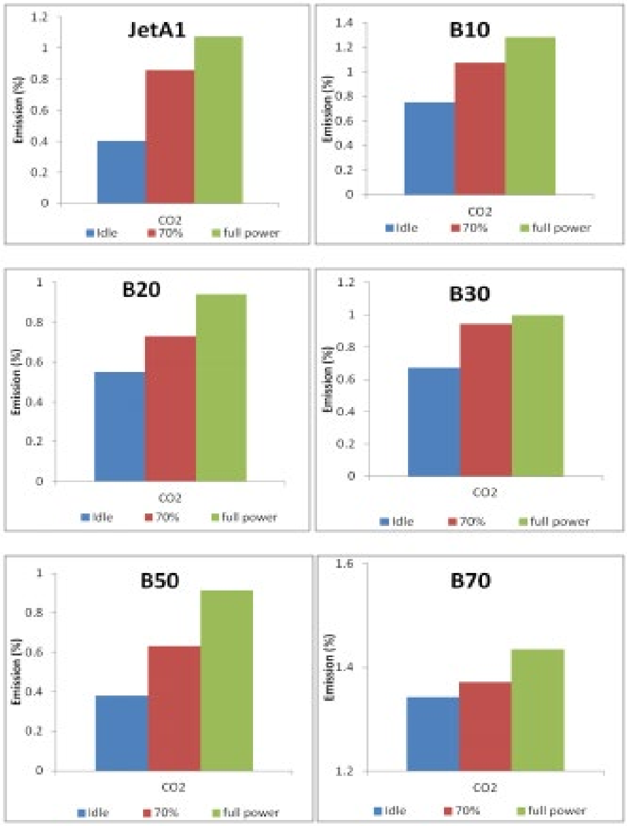


Fig.1: $CO_2$ Emissions as a function of throttle

NO and $NO_2$ emissions were measured as well as NOx as a function of throttle settings for all the fuels tested. From NO and $NO_2$ measurements, NOx was obtained. B70 produced significantly higher NOx emissions at all throttle settings than other fuels. Figure.2 shows NOx emission as a function of throttle settings for all fuels. The NOx emissions from B10 and B20 were very close and about 35% lower than B70. B50 produced a significantly low emission of about 62% lower than B70. Higher NOx emissions from B70 could be related to oxygen content in the biodiesel as compared to Jet-A1 [11]. Lower CO from biodiesel was considered that the combustion was assisted by the oxygen in the biodiesel. However, oxygen in the biodiesel had an adverse on NOx in the lower throttle setting.

It can be observed from Figure.3 below that CO emission in Jet A1, B10, B20 and B30 decreases from idle position to 70% power and increases again at full power. B20 had the lowest rate of CO emission of 370 ppm and B10 had the highest rate of CO emission of 427 ppm at 70% throttle setting.

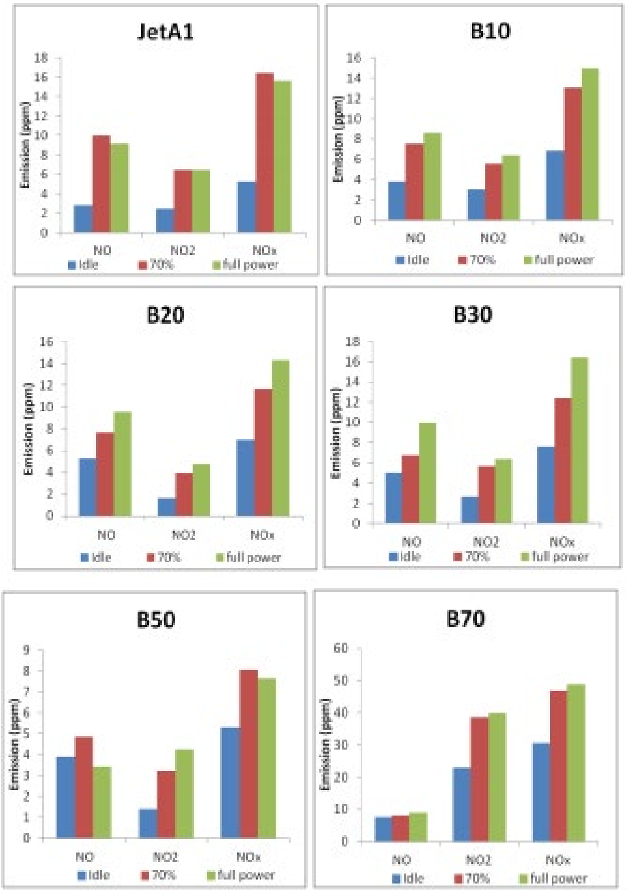


Fig.2: NOx Emissions as a function of throttle

The emission of CO for Jet A1 was higher than only B20 and lower than other fuels tested. This result could be due to improper mixing and incomplete combustion of fuel. THC for the fuels at different throttle positions were measured and presented in figure.3 below. THC emission in all the fuels tested increases with increase in throttle setting.B50 had significantly higher THC emission than the other fuels. This is because of higher throttle setting and flame temperatures [11]. Idle throttle setting would reduce hydrocarbon emissions of B50. Increase of fuel flow for B70 was affected by the visual smoke trail as a result of inefficient evaporation.

The $SO_2$ emission as a function of throttle settings for the fuels tested with the micro gas turbine engine is shown in Figure 4.20. B70 having the highest emission rate of $SO_2$ of about 8.0 ppm. It can be seen that the emissions increases as the throttle position increases. Jet A1 and B20 had almost the same rate of $SO_2$ emission of 1.6 ppm. B30 had an emission of about 3.0 ppm. B10 had the lowest $SO_2$ emission at all throttle settings which could be due to the biofuel production method or the feedstock used.

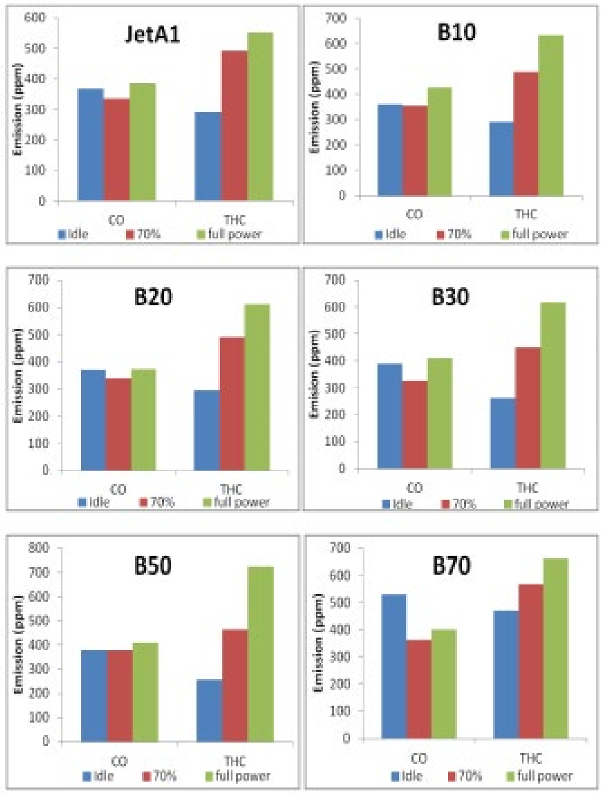


Fig.3: CO&THC Emissions as a function of throttle

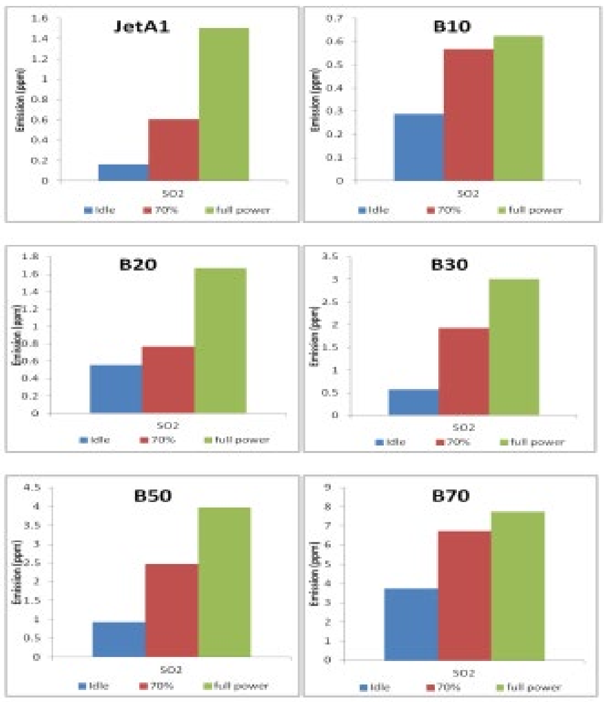


Fig.4: $SO_2$ Emissions as a function of throttle

## IV. CONCLOSIONS

In this work, gaseous emissions were analyzed for Jet A1 and various biodiesel blends using a micro gas turbine engine. B50 was seen to have the lowest $CO_2$ and NOx emission. However, B70 had the highest $CO_2$ and NOx emission at all throttle settings which could be as a result of effect from land use, production method or the feedstock used. B20 had the lowest emission of CO and THC while B10 had the highest emission. B10 was investigated to emit the least $SO_2$ and B70 emitted the most. High emission from higher blends of biodiesel could be as a result of poor atomization, vaporization and mixing which is more difficult with higher concentration of biodiesel in the blends.

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