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Synthetic kerosene as an Alternative Fuel for Commercial Aviation

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ABSTRACT

Due to the finite supply of petroleum fuels and increasing demand for energy worldwide, the development of alternative sources is becoming necessary. Renewable fuels are also in demand to reduce the carbon footprint of aviation. Many alternative aviation fuels are being considered by industry and research groups. The most viable alternatives are synthetic kerosene, Fatty Acid Methyl Ester (FAME), hydrogenated vegetable oils, liquid hydrogen, methane, and ethanol/methanol. GTL (Gas To Liquid) will be tested and compared to JetA1 fuel regarding their gaseous and particulate emissions. A re-commissioned Artouste MK113 APU gas turbine engine was used. It is a single spool gas turbine engine, in which a centrifugal compressor is driven by two-stage turbine through a single rotating shaft. The engine was running at two power conditions: idle and full power. CO_2, CO, UHC NOx, and NO_2 fractions were measured and compared for both fuels at two conditions. The results showed that CO2 decreased as the hydrogen to carbon ratio increased. Thus, GTL fuel produced a similar level of NOx compared to JetA1 and a slight reduction in CO. A remarkable reduction in UHC was observed at all conditions for higher H/C fuel.

Keywords: gas turbine, gaseous emissions, alternative fuel

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تطبيقات الكيروسين الصناعي كوقود بديل في مجال الطيران

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الملخص

بسبب العرض المحدود للوقود الاحفوري وزيادة الطلب على الطاقة في جميع أنحاء العالم أصبح ايجاد وتطوير مصادر بديلة أمرًا ضروريًا. ان الوقود المتجدد مطلوب أيضًا لتقليل البصمة الكربونية للطيران عن طريق ايجاد العديد بدائل وقود الطائرات من قبل الشركات المصنعة ومراكز الابحاث. يعتبر الكيروسين الصناعي هو اكتر البدائل الأكثر قابلية للتطبيق كدلك ميثيل استر الأحماض الدهنية ، الزيوت النباتية المهدرجة ، الهيدروجين السائل ، الميثان ، والإيثانول / الميثانول. في هدة الورقة سيتم اختبار الكيروسين الصناعي (غاز إلى سائل) ومقارنته بوقود الطائرات العادي (الكيروسين) من حيت الانبعاثات الغازية والجسيمات المتطايرة. تم تجربة الوقودين علي محرك توربين الغازي. تم تشغيل ضاغط الطرد المركزي بواسطة توربين من مرحلتين من خلال عمود دوار واحد وكان المحرك يعمل في حالتي: العادية والقوة الكاملة. تم قياس ومقارنة نسب اول اكسيد الكربون، وثاني اكسيد الكربون، اكاسيد النيتروجين، الهيدروكربونات الغير محترقة وثاني اكسيد النيتروجين في كلا الحالتين. أظهرت النتائج أن ثاني أكسيد الكربون ينخفض كلما زادت نسبة الهيدروجين إلى الكربون في الوقود. كدلك اظهرت الدراسات ان الكيروسين الصناعي ينتج نسبة متقاربة من اكاسيد النيتروجين وانخفاض بسيط في اول اكسيد الكربون مقارنا بوقود الطائرات المعتاد. واتبت النتائج ايضا انخفاض كبير جدا في الهيدروكربونات الغير محترقة باستخدام الوقود البديل في كلا الحالتين.

الكلمات المفتاحية: التوربينات الغازية ، الانبعاثات الغازية ، الكيروسين الصناعي، الكيروسين

Introduction

Due to the finite supply of petroleum fuels and increasing demand for energy worldwide, the development of alternative sources is becoming necessary. Renewable fuels are also in demand to reduce the carbon footprint of aviation. There are many alternative aviation fuels listed in Fig.1 being considered by industry and research groups. The most viable alternatives are synthetic kerosene, Fatty Acid Methyl Ester (FAME), hydrogenated vegetable oils, liquid hydrogen, methane, and ethanol/methanol [1,2]. For the short term, the synthetic liquid fuels of major interest will be largely derived from biomass, coal, oil shale/tar sands, and heavy oil. For the longer term, liquefied gaseous fuels (methane and hydrogen) are among the candidate fuels now being considered. All these fuels must be compatible with the engine and fuel-system requirements and with aircraft design features and operational procedures [1,2].

Synthetic word is used to describe fuels derived from nonpetroleum feedstock, such as gas, coal, and biomass [1,2,3]. Fischer-Tropsch (FT) is a process where the mixture of carbon monoxide and hydrogen (syngas) is converted into higher molecular weight - hydrocarbons Fig.2. The process begins with the gasification of the feedstock to produce a mix of carbon monoxide and hydrogen (syngas), which then goes through a catalysed chemical reaction to produce liquid hydrocarbons. The properties of synthetic kerosene are varying depending on the hydrogen to carbon ratio, catalyst, and process conditions. Since the FT synthesis starts with carbon monoxide, any source of carbon can potentially be used. If the synthetic kerosene is produced from coal, the conversion is called coal to liquid (CTL); natural gas (NG) can also be used as the starting material and is called gas to liquid (GTL), and most of the current plants use NG [1,2]. Thus, biomass to liquid (BTL) is produced from biomass as a starting material by going through a gasification step to produce carbon monoxide. The main benefits of FT transportation fuels are that they are large, secure domestic supply, and clean burning fuel with very low nitrogen, aromatics, and sulfur [1,2,3].

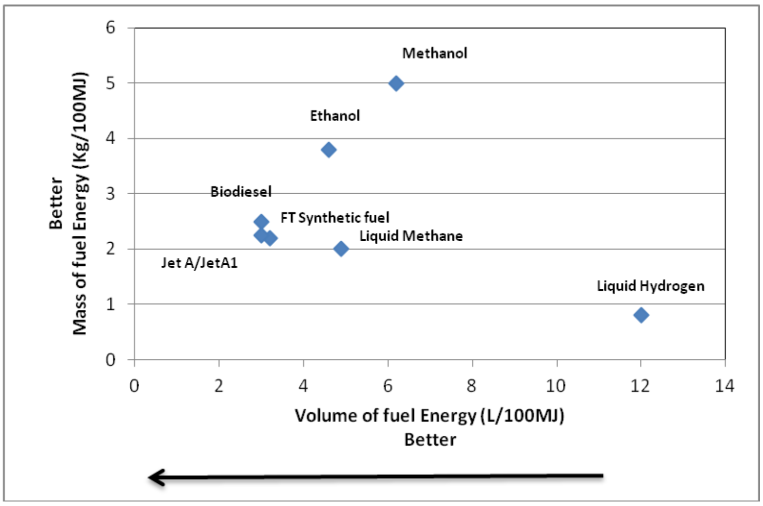

Figure 1: Alternative aviation fuels

Synthetic kerosene has close to zero sulfur- and nitrogen-contained compounds compared to conventional jet fuel, with there being no SOx or sulphuric acid aerosol emissions.

$$CO+H_2 \quad \rightarrow (CH_2)_n+H_2O$$

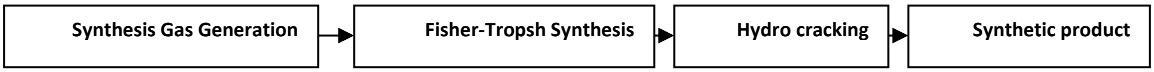

Figure 2: Production of synthesis product process

The fuel is also free of aromatic compounds, which will improve thermal stability, lead to cleaner burning, and reduce fuel burn and CO2 emissions. However, there are negative attributes of using synthetic kerosene with no aromatic compounds in aviation sectors, including poorer lubricating properties, lower volumetric heat content, a possible contributor to fuel system elastomer leakage, and increased CO_2 emissions during its manufacture. To increase the density of synthetic kerosene and avoid leaking, blending with conventional jet fuel is the solution, with many industries using 8% aromatic compounds as a guiding minimum [4,5]. In this paper, gaseous emissions will be studied using an Auxiliary power unit (APU) at idle and full power conditions. JetA-1 will be used as a base fuel and compared to GTL fuel.

Materials and Methods

An Artouste MK113 APU engine was used as a test bed for the emissions measurements. It is a single spool gas turbine engine, in which a centrifugal compressor is driven by two stage turbine through a single rotating shaft [1,8]. All operating parameters of the engine such as fuel flow rate, RPM, exhaust temperatures, pressure, and fuel consumption were monitored and recorded throughout the experiment.

Fuel compositions were shown in Table 2. It shows the ratio of hydrogen to carbon, aromatics content, sulfur content, and density of the testing fuels. Two separate fuel tanks were used for JetA1 and GTL fuels respectively. The neat conventional kerosene-based JetA1 was used as the reference fuel. All fuels were tested for engine exhaust gaseous and particle emissions.

Table 1: Fuel properties Fuel symbol Fuel compositions

Fuel compositions	Sulphur ppm	H/C Ratio	Aromatics (%wt)	Cycloalkanes (%wt)	Density kg/m^3
JetA1	400	1.89	20.5	13.5	801.9
100% GTL	<5	2.19	0	0	737.6

Theory and Calculation

All gaseous emissions including carbon monoxide (CO2), carbon monoxide (CO), total hydrocarbon (UHC), and nitrogen oxides (NOx) were measured at idle and full power and converted to their perspective emissions indices using the conventional method for the computation of emissions index (EI m) using the equation below and presented in Figs.3 to7 respectively.

$EI\ n=EICO2\ x\ (N0\ /\ M\ (CO2)\ x10^{6}$

EIn: The number of particles per kg fuel burned, P/kg-fuel

$EICO_2$: mass emissions index of CO_2, 3160g/kg for JetA1.

N0: the number of the particles per unit of volume of exhaust sample, P/cm^3

M (CO_2): mass of CO2 per volume of exhaust samples, kg/m3.

M (CO2)=Cco_2 x (44/29)x ρair,

CO_2: is the CO_2 concentration, %.

ρair: is the density of air, $1.2kg/m^3$.

44 and 29 are the molar mass of CO_2 and air respectively.

Results and Discussions

Gaseous emissions from both JetA-1 and syntactic fuels measured from the APU engine are illustrated in Figs.3 to 7 for all fuels tested. The results showed emissions index (EI m g/kg fuel) for CO_2, CO, UHC, NOx, and NO2 fractions respectively. The measured CO2 emission index is presented in Fig.3, CO_2 decreased as the hydrogen to carbon ratio increased and GTL had the lower CO2 of about 3000 g/Kg with a H/C ratio of about 2.2 compared to base fuel.

The EI of CO and UHC emissions for all fuels are presented in Figs.4&5. The results for both fuels are similar and at full power. The CO average values were 75-90 g/kg at idle and ~25 g/kg fuel at full power. The UHC average emissions were 15-25g/kg at idle and ~4g/kg at full power respectively. Significant reductions in CO and UHC emissions were observed for GTL. At idle conditions, it reduced CO and UHC EI by 29% and 44% respectively relative to JetA1. At full power, GTL reduced UHC emissions by approximately 44% compared to JetA1 but there was almost no CO reduction.

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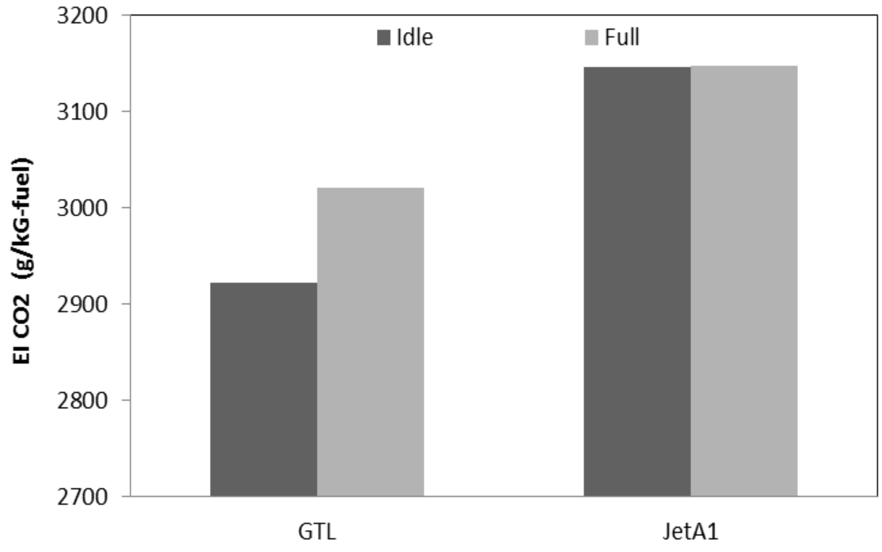

Figure 3: $EICO_2$ emissions (g/Kg-fuel) for different fuels at idle and full power.

The reductions in UHC by GTL are reflected in particle emissions as will be shown later. JetA1 had the highest UHC and thus the highest particle numbers and mass. The GTL had the lowest UHC and therefore the lowest particle number and mass emissions. The correlation was thought to be related to gas-to-particle conversion and condensation effect.

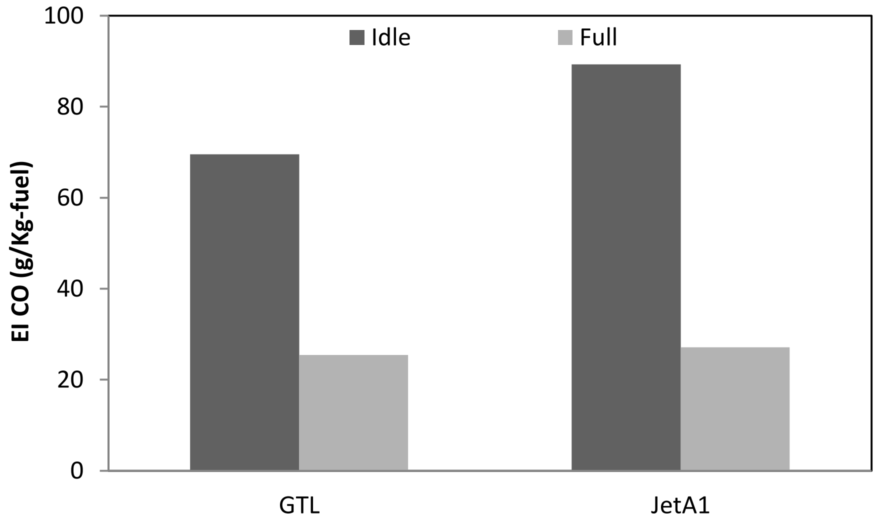

Figure 4: EICO emissions (g/Kg-fuel) for different fuels at idle and full power.

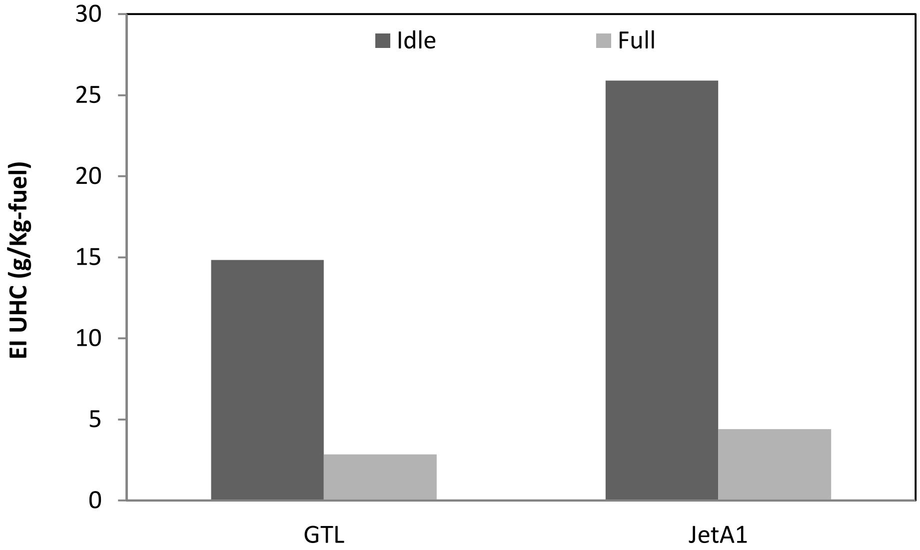

Figure 5: EI UHC emissions (g/Kg-fuel) for different fuels at idle and full power.

EI m- NOx (g/kg-fuel) for all fuels are presented in Fig.6. NOx emissions for both fuels had a value of ~3.5 g/kg-fuel at full power and ~2.1 g/kg-fuel at idle. The GTL fuel had lower NOx emissions (~2g/Kg) relative to JetA1. Overall, both fuels showed similar NOx emissions. This conclusion is in good agreement with other people's research [9-11].

NO2/NOx fractions for both fuels are presented in Fig.7 for idle and full power conditions respectively. The results showed that NO2 made a major contribution to the total NOx at idle (53-57%), whereas at full power NO2 contributed 34-40% of total NOx. These findings are very close to Timko et al using PW308 engine and Wood et al using APU of CFM56 [7,8]. These results showed that NO2 has an opposite trend compared to NO and NOx, higher at idle and lower at full power and it is not flame temperature dependent. It is considered that the higher NO2 fractions at idle were due to more oxygen available at idle to oxidize NO into NO_2.

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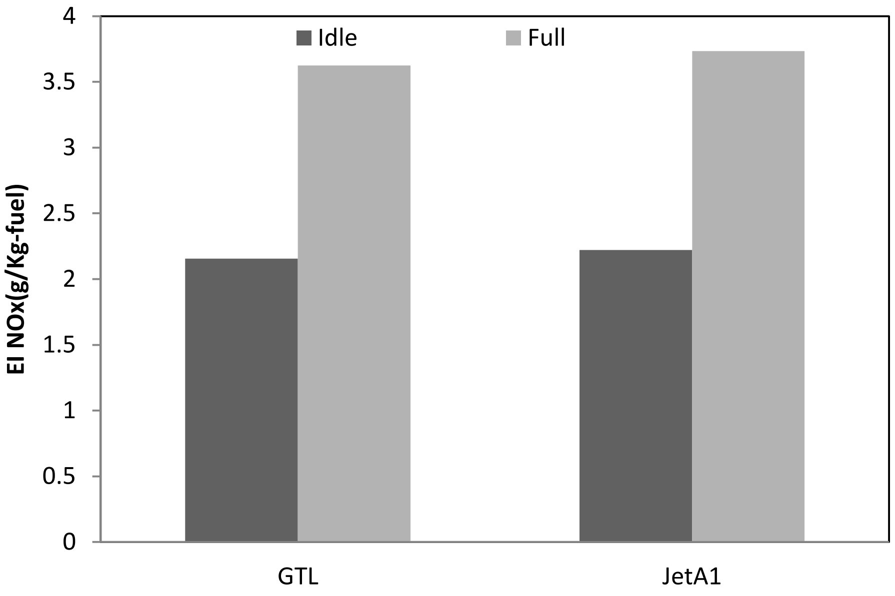

Figure 6: EI NOx emissions (g/Kg-fuel) for different fuels at idle and full power.

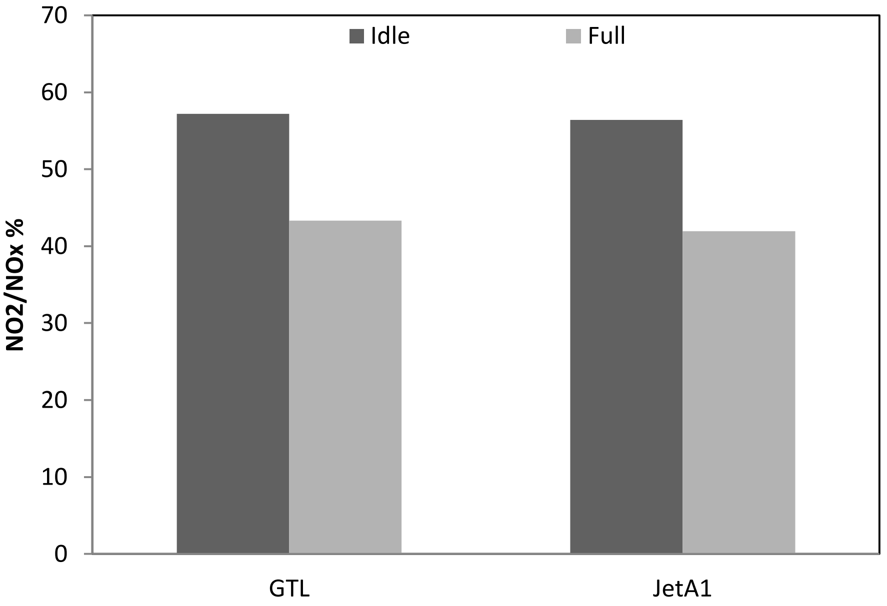

Figure 7: NO2/NOx % for different fuels at idle and full power.

Conclusions

Conventional JetA1 and GTL were tested using an APU engine. The influence of fuel H/C ratio and engine power on the particle number and mass size distributions and gaseous emissions were investigated. The results show that:

1) Most of the fuels had very close hydrogen/ Carbon ratios (~2), and the amounts of CO2 emissions are similar. However, CO2 decreased as the hydrogen to carbon ratio increased and GTL had the lowest CO2 about (3000 g/Kg) with a H/C ratio of about 2.2 compared all fuels.

2) At idle conditions, there are slight reductions in CO and UHC emissions for all fuels compared to JetA1. However, a significant reduction in CO (~28%) and UHC (~44%) was observed with GTL fuel

3) Both fuels produce a similar level of NOx emissions and fuel properties have little impact on NOx emissions under both conditions. NO2/NOx fraction for all fuels was about 55% and ~40% at idle full conditions respectively.

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