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METHOD OF PRELIMINARY EVALUATION OF BIOCOMPONENTS INFLUENCE ON THE PROCESS OF BIOFUELS COMBUSTION IN AVIATION TURBINE ENGINES

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Abstract

The aim of this article is presentation of the new method of preliminary evaluation of biocomponents influence on the process of biofuels combustion in aviation turbine engines. This method is based on the tests of evaluated biofuels on engine stand MiniJetRig equipped with small turbine engine. The idea of this new method is to compare the combustion process of evaluated biofuel with the combustion of reference fuels. The reference fuel used in presented research was mineral Jet A1. Two compositions of pure hydrocarbons were blended with Jet A1 fuel and tested using MiniJetRig. The main criterion of combustion process assessment was CO concentration in exhaust gases. As the final criterion of evaluated biofuel the $\Delta_{CO} = [CO_{Wx} - CO_{Jet}]$ *was adopted, where* CO_{Wx} *– the concentration of CO in exhaust gases emitted during combustion of evaluated fuel and* CO_{Jet} *– the concentration of CO in exhaust gases emitted during combustion of Jet A1 fuel. This method was preliminary verified using HEFA biofuel previously accepted for aviation application. The obtained results qualify this biofuel as similar to Jet A1 ones – the DCO was within limits –30 – +20. The presented method needs further research, using much more evaluated fuels, to confirm their usefulness for laboratory pre-selection of new biofuels.*

Keywords: *Fuels for aviation turbine engines, biofuels, synthetic hydrocarbons, engine tests*

1. Introduction

The petroleum fuels for aviation application consist of hydrocarbons of 8 to 20 carbon atoms in molecule. These conventional fuels are accepted by aviation engines manufacturers and are used commonly all over the world. The typical composition of mineral Jet fuel is as follows:

- ca. 25 % n-paraffin,
- ca. 35 % izo-paraffin,
- ca. 20 % cyclo-paraffin,
- ca. 20 % aromatic hydrocarbons.

Development of air transport has made its share in emission of CO_2 becomes significant. It is the reason of high interest in synthetic aviation fuels produced from biomass [1, 2, 3, 4, 5]. For this kind of fuels, the CO_2 emission is calculated as zero. The chemical structure of chosen, previously accepted by aviation engines manufacturers biofuels is shown in Tab. 1.

Tab. 1. Chemical structure of chosen, previously accepted by aviation engines manufacturers biofuels [6]

Hydrocarbons	HEFA/HVO	FT-SPK/A	FT-SPK	SIP	ATJ-SPK
n- paraffin	X	X	X	–	–
Izo- paraffin	X	–	–	X	X
Olefins	–	X	X	–	–
Aromatic	–	X	Small amount	–	–
HEFA/HVO – hydrotreated vegetable oil, FT-SPK/A – Fischer – Tropsh + aromatic hydrocarbons, FT-SPK – Fischer – Tropsh, SIP – , ATJ-SPK – alcohol to jet.					

The specific requirements of aviation fuels need technologies of biofuel production, which give products of stable chemical structure and stable quality. This is a fundamental requirement [15, 16, 17, 24]. The biofuel dedicated aviation should consists of compounds (mainly hydrocarbons) of strictly determined chemical structure, i.e. n-paraffins, iso-paraffins, aromatic hydrocarbons and others. This chemical structure depends on the raw material, technology of biomass conversion to liquid fuels, methods of products upgrading as well as final fuels storage and transport techniques. Below there is shown the sensitivity of different technologies of biomass conversion to aviation biofuels on the kind and quality of raw material (biomass).

HEFA/HVO (fats) ➔ FT-SPK/A = FT-SPK ➔ SIP (sugarcane) ➔ ATJ-SPK

The sensitivity of biofuels on raw materials quality decreases

Current level of biofuels production technologies justifies the pathway of new fuels certification by engines and aircrafts manufacturers. According to ASTM D4054 – Standard Practice for Qualification and Approval of New Aviation Turbine Fuels and Fuel Additives [7] standard / procedure each new fuel / biofuel is certified along the live cycle from raw material to the end product. Such certified fuel is tested according to laboratory procedures, stand tests, tests in engine house and finally fly tests.

As it is shown in Table 1, the chemical structure of synthetic biofuels is different from mineral jet fuels. It is the reason that aviation engines manufacturers have accepted only blends of synthetic biofuels and mineral jet fuel [20, 21, 22, 25].

The currently accepted biofuels are produced by very small number of companies in selected plants. The EU goal significantly to increase the consumption of biofuels by air transport needs new procedures of aviation biofuels certification. Forecasting great, volume of biofuels on aviation fuels market make use current procedures of acceptance very difficult and expensive.

The aim of this article is presentation the idea of new, quicker and chipper methodology of biofuels selection and acceptance before final tests in engine house and fly tests. This methodology is based on assessment of combustion process in small turbine engine and comparison tests results obtained for new tested biofuel with the results obtained for reference fuels.

2. Reference fuels

Biofuels for aviation turbine engines can be produced using different raw materials and technologies and consequently their chemical structure is different than mineral jet fuel as well as they differ each other. It is known that changes of fuels hydrocarbon structure influence on their behaviour during combustion process in an engine [9, 10, 12, 13]. This influence can be seen when aircrafts engine operates under critical conditions e.g. when it is necessary to increase quickly engines thrust. This influence can be indirect one as well, i.e. when biofuels hydrocarbons cause deposits formation in such elements of fuelling system as injector. The properties of known and produced currently biofuels, listed above, are similar to mineral jet fuels, so the physicochemical properties do not provide sufficient information about the possible problems and threats during engines operation.

Laboratories, which deal with the mechanism of fuels combustion process, in special reactors, use often the “surrogate fuels”, i.e. individual hydrocarbons or the mixture of several (two or three) hydrocarbons, as the model of liquid fuel or biofuel. The idea presented in this article is to use such surrogate fuels as the reference once, test them using small, laboratory turbine engine and prepare the ranking list of these reference fuels taking into account their similarity with conventional Jet fuel. The reference fuels will be divided on two groups: first – similar in combustion process to Jet fuel, the second – unlike to Jet fuel [11, 14, 18, 19]. The new, unknown biofuel will be tested using laboratory tests and engine test on small, laboratory turbine engine and the obtained results will be compared with ranking list of reference fuels. The tested biofuel will be directed to further engine tests and fly tests only in case the results of test on laboratory turbine engine will be similar to results obtained for reference fuel, which belongs to first group.

3. Methodology

The candidates on reference fuels were prepared using pour hydrocarbons of chemical structure similar to products of HEFA technology. The following mixtures were prepared:

Tab. 2. The mixtures of pure hydrocarbons used in the research

Mixture No.	Octane (C_8)	Undecane (C_{11})	Pentadecane (C_{15})	Heptadecane (C_{17})
M2	0	30% (V/V)	35% (V/V)	35% (V/V)
M3	0	0	50% (V/V)	50% (V/V)
M4	0	50% (V/V)	50% (V/V)	0
M5	50% (V/V)	50% (V/V)	0	0

Each of the mixture was blended with mineral Jet A1 fuel to produce reference fuels listed below.

Tab. 3. The list of prepared reference fuels

Reference fuel No.	Mixture of pure hydrocarbons No.	The composition of reference fuel
W1	–	Jet A1
W2	M2	90% (V/V) Jet A1 + 10% (V/V) M2
W3	M3	90% (V/V) Jet A1 + 10% (V/V) M3
W4	M4	90% (V/V) Jet A1 + 10% (V/V) M4
W5	M5	90% (V/V) Jet A1 + 10% (V/V) M5

Prepared reference fuels were tested in laboratory tests according to ASTM D1655-16c Standard Specification for Aviation Turbine Fuels [6]. The physicochemical properties of reference fuels were compared with properties of mineral Jet A1 fuel. Basing on laboratory tests results Jet A1 and two of reference fuels containing mixtures of pure hydrocarbons were chosen for engine tests.

The engine tests were conducted on miniature turbine engine on MiniJetRig stand [8]. The procedure of fuels testing was developed in Air Force Institute of Technology and described at [8]. This procedure assumes the following parameters of engine operation:

– the rotational speed increase stepwise,

– the rotational speed chosen for fuels evaluation: 39 000 rpm, 70 000 rpm, 88 000 rpm and 109 000 rpm,

– the parameters measured during test: fuel consumption, rotational speed, temperatures in front of combustion chamber, in combustion chamber and behind the turbine, concentration of CO_2, CO, CxHy, PM and NOx in exhaust gases

4. The results

The physicochemical properties of prepared reference fuels are show in Tab. 4.

It was concluded that the W5 reference fuels properties are the most similar to the properties of mineral Jet A1 fuel (W1) and the properties of W3 are east like W1. Basing on the results three of reference fuels were chosen for engine tests: W1, W3 and W5.

The results of engine tests are shown in Tab. 5 and 6.

Tab. 4. The results of laboratory tests of reference fuels

Parameter	W1 (Jet A1)	W2	W3	W4	W5
Calorific value, [MJ/kg]	43.40	43.61	43.67	43.53	43.62
Density at 15ºC, [kg/m^3]	788.0	785.8	786.7	784.9	781.8
Kinematic viscosity at –20ºC [mm^2/s]	2.985	3.325	3.461	3.208	2.862
Kinematic viscosity at +40ºC, [mm^2/s]	1.049	1.128	1.154	1.099	1.024
Flow temperature [ºC]	< –66.1	–33	–27	–42	–63
Surface tension	25.32	25.12	25.28	24.54	24.93
Freezing point [ºC]	–63.0	–25.0	–21.0	–35.5	–60.5

Tab. 5. The CO concentration measurements results during the tests on MiniJETRig

Rotational speed [rpm]	Fuel		
	Jet A1	W3	W5
39 000	1437	1172	1449
70 000	1666	1362	1717
88 000	1269	923	1264
109 000	804	864	858

Tab. 6. The CxHy concentration measurements results during the tests on MiniJETRig

Rotational speed [rpm]	Fuel		
	Jet A1	W3	W5
39 000	128	158	152
70 000	103	137	131
88 000	80	111	106
109 000	90	125	111

It was assume, that the criterions of biocomponent evaluation are the values of Δ_{CO} and Δ_{CxHy} treated as similarity criterion. Their values were calculated according to the following equations:

$$\Delta_{CO} = [CO_{Wx} - CO_{Jet}], \tag{1}$$

$$\Delta_{CxHy} = [CxHy_{Wx} - CxHy_{Jet}]. \tag{2}$$

The combustion process of tested fuel is treated as similar to the combustion process of Jet A1 when values of Δ_{CO} and Δ_{CxHy} are close to zero. Basing on the results shown in Tab. 5 and 6, the values of Δ_{CO} and Δ_{CxHy} were calculated. The obtained results are shown on Fig. 1 and 2.

The obtained results indicate that the Δ_{CO} can be the criterion of similarity of combustion process of the tested fuel to the combustion process of Jet A1. The Δ_{CxHy} does not differentiate tested fuels and cannot be the criterion of similarity.

In relation to Δ_{CO}, the reference fuel W5 was classified to similar ones to Jet A1 and W3 to the second group – unlike to Jet fuel.

Concluding the obtained results allow to determine the limited values of Δ_{CO} in the range between +100 ppm and –100 ppm. If the new unknown fuel gives in engine Δ_{CO} in this range of values this fuel is accepted for the further research in engine house. Important is to use during such tests as reference fuel W1 the same Jet A1 fuel as was used to prepare blend with the tested biocomponent.

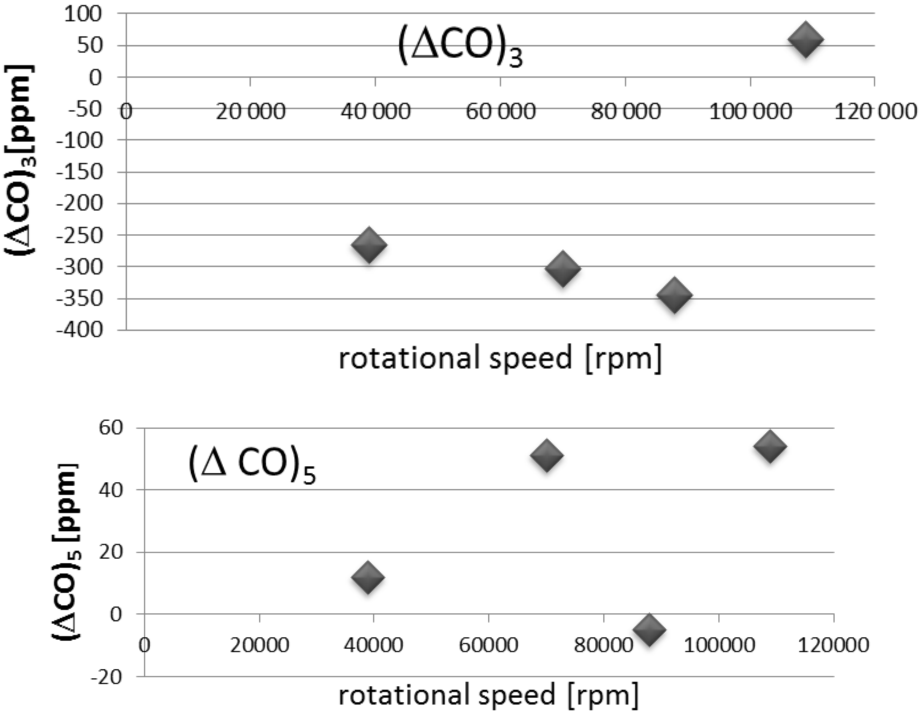

Fig. 1. The MiniJetRig results – Δ_{CO} *values vs. rotational speed for W3 and W5 reference fuels*

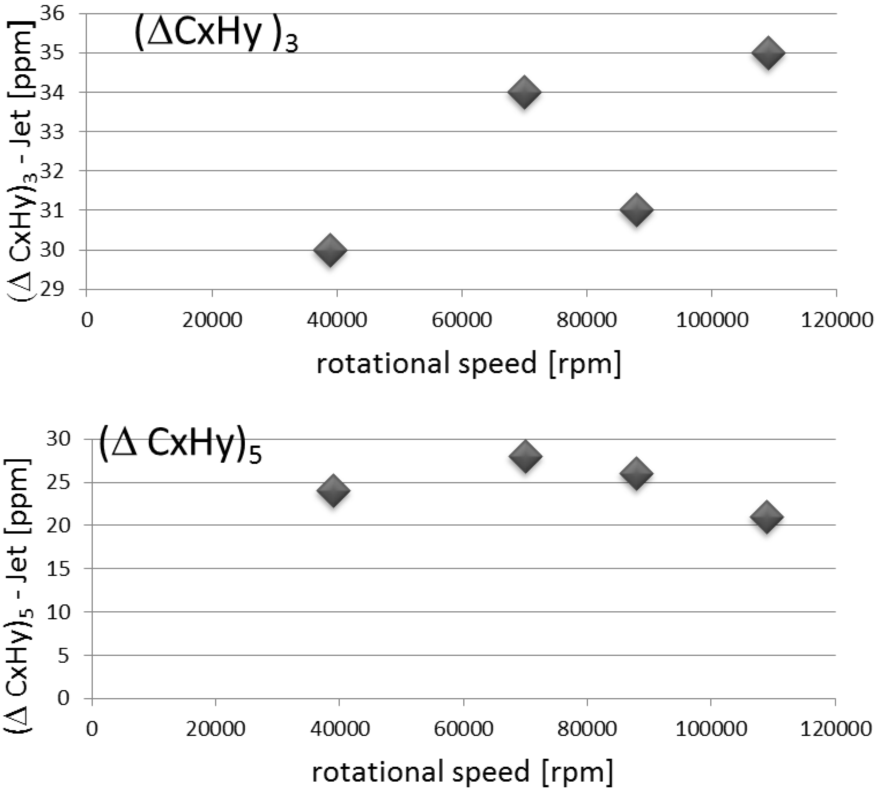

Fig. 2. The MiniJetRig results - Δ_{CxHy} *values vs. rotational speed for W3 and W5 reference fuels*

The verification of this proposed method was performed using commercial new biofuel for Jet engines, containing 50% (V/V) of Jet A1 and 50% (V/V) HEFA biocomponent. This fuel was tested in laboratory and on MiniJetRig according to shown above methodology. The obtained results are shown in Tab. 7 and on Fig. 3.

Tab. 7. The results of MiniJetRig tests for the new biofuel containing commercial HEFA biocomponent

Rotational speed [rpm]	HEFA CO [ppm]	Jet A1B CO [ppm]
39 000	1310	1321
70 000	1507	1520
88 000	1125	1113
109 000	673	703

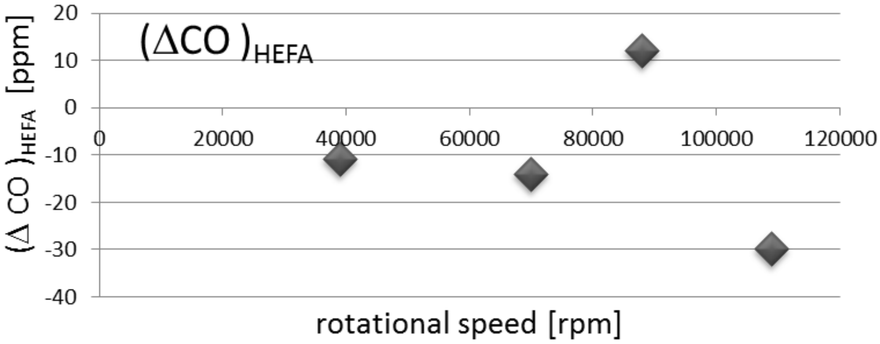

Fig. 3. The Δ_{CO} values obtained for evaluated new commercial HEFA biofuel.

5. Conclusions

The results obtained during research described in the article leads to the following conclusions:

– The standard laboratory tests according to ASTM requirements are not the enough criterion of evaluation the new unknown fuels / biofuels behaviour during combustion in turbine engine.

– The tests on MiniJetRig stand conducted according to AFIT procedure allow for the preliminary evaluation of the new fuels / biofuels behaviour during combustion in turbine engine.

– The proposed criterion of evaluation is Δ_{CO} calculated on the basis of MiniJetRig tests results, which value should be in the range between –100 ppm and +100 ppm.

The new commercial HEFA biofuel, blended with Jet A1 mineral fuel (50x50) was tested using presented in this article methodology. This biofuel was accepted previously for aviation application. The obtained MiniJetRig stands results indicate that this biofuel should be accepted for the further engine tests. This conclusion is agree with information about the previous acceptance of this biofuel for aviation application, so the worked out and describe in this article method has been pre-verified.

The further research using more reference fuels and more new biofuels is needed for the worked out methodology development and verified.

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