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THE EFFECT OF ADDING 2-ETHYLHEXANOL TO JET FUEL ON THE PERFORMANCE AND COMBUSTION CHARACTERISTICS OF A MINIATURE TURBOJET ENGINE

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Abstract

There are currently many studies undergoing in the field of using alternative fuels for supplying different types of propulsion units. The ASTM standard in the aerospace industry, allows using five different technologies of manufacturing synthetic components apart from standard oil-based fuel for the propulsion of turbine engines (as a blend up to 50% with conventional fuel). One of these is a technology associated with the process of converting alcohols (isobutanol) to jet fuel – Alcohol to Jet (ATJ). In the research performance, emission parameters were measured on laboratory test rig with miniature turbojet engine (MiniJETRig). The test rig has been created in Air Force Institute of Technology for research and development works aimed at alternative fuels for aviation. The miniature engine was fuelled with conventional jet fuel – Jet A-1 and blend of Jet A-1 with 2-ethylhexanol. The results for this blend were compared with the results obtained for neat Jet A-1 fuel in terms of different engine operating modes, according to specified methodology. The conducted tests did not show significant differences in engine operating parameters (thrust, fuel consumption and thrust specific fuel consumption) and the values of CO, CO_2 and NO_x emission indices between the tested fuels. The engine tests took place in similar ambient conditions. Laboratory tests of selected physicochemical properties were also carried out for both fuel samples.

Keywords: *alternative fuels, alcohol to jet, combustion process, miniature jet engine, exhaust emission*

1. Introduction

Alternative fuels are widely used and implemented in on-land transport, cars, vehicles, power generators. Regarding aircraft engines, in the ASTM D7566 [1] there are specified approved five different technologies of synthetic blending components, that can be used up to 50% with conventional fuel. One of them is the processing of alcohols on fuels – Alcohol to Jet (ATJ). The process involves creating a synthetic component from alcohol. Isobutanol $C_4H_{10}O$ is obtained from biomass in the first step, which is then subject to a dehydration reaction, which results in the formation of olefins with a short carbon chain. During the oligomerization, short olefin chains form longer, with a C_8-C_{16} isoolefin structure [1, 2, 21]. The isoolefin hydrogenation and fractionation reaction provide us with a synthetic paraffin kerosene (SPK), in the form of an isoparaffin blend.

The authors of several below articles showed the investigative results of alcohols-jet fuel blends demonstrating examples of low exhaust emissions, good calorific value and suitable engine characteristics.

Chuck and Donnelly [6] tested nine potential alternative fuels derived from sustainable sources and checked them for their compatibility with aviation kerosene (Jet A-1), i.e. basic properties of neat samples and fuel blends were verified: kinematic viscosity, cloud point, distillation calorific value, flash point and density. The chosen fuels were n-butanol, n-hexanol, butyl levulinate, butyl butyrate, ethyl octanoate, methyl linolenate, farnesene, ethyl cyclohexane and limonene. The authors concluded that esters were more compatible with aviation kerosene than alcohols and of the potential fuels studied, only limonene was found to fall within the required specification.

Dagauta et al. [7] focused their research on the oxidation kinetics of blends of gas-to-liquid (GtL) jet fuel with 20% vol. of 1-hexanol and compared them with neat Jet A-1. Finally, the authors presented the results of the oxidation modelling of GtL-jet fuel (n-decane, iso-octane, n-propylcyclohexane, and 1-hexanol) using a detailed kinetic reaction mechanism and concluded that a reasonable model of the oxidation kinetics of the fuel was obtained.

Another example of an experimental and modelling study of synthetic jet fuels burning velocities was presented by Th. Kick et al. [18]. The authors have chosen several existing and potential alternative jet fuels and focused on their heat release: GtL (representing a Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK)), a fully synthetic jet fuel (FSJF: Coal-to-Liquid (CtL)), and blends of GtL with 20% of 1-hexanol or 50% of naphthenic cut, respectively. The burning velocities of the different fuel-air blends were studied by applying the cone angle method. Finally, the authors concluded that the reaction model reached good agreement between measured burning velocity and predicted flame speeds for all four fuels studied. The results showed that the investigated fuel blends can be potentially used as alternative aviation turbine fuels.

Examples of alternative fuels emission characteristics studied R. Bhagwan et al. [4]. Emissions characteristics of lean, turbulent, partially premixed swirled flames of synthetic fuels along with a standard Jet A-1 fuel were considered. The investigated synthetic fuels were FSJF, FT-SPK, FT-SPK with 20% of hexanol and FT-SPK with 50% of naphthenic cut. The exhaust gas components: carbon dioxide (CO_2), carbon monoxide (CO), unburned hydrocarbons (UHC) and nitric oxides (NO and NO_2) were measured at several combustor pressure levels. The results showed that the NO_x formation behavior of the investigated fuels were attributed to their probable different degrees of mixing with air in the combustor. However, for the tests performed at higher pressure conditions close to the aero-engine combustion systems, the emissions characteristics of tested synthetic fuels were very similar to Jet A-1.

C. J. Mendez et al. [19] focused in their study on the effect of 1-butanol/Jet A blends on the performance and emission characteristics of a small gas turbine engine. The authors examined the performance characteristics, the thrust, thrust-specific fuel consumption, turbine inlet temperature, exhaust gas temperature and the emission characteristics (thrust-specific emission indices of CO and NO_x). As it was revealed the operational thrust range of the engine for butanol-containing fuels was reduced when compared to that of Jet A fuel and the NO_x and CO emission indices were lower for butanol and butanol blends compared to those with Jet A. At the end authors concluded that the blends of butanol with Jet A could be promising alternate fuels with similar operational range and comparable thrust to that of Jet-A, but with less CO and NO_x emissions.

B. Gawron et al. [11] conducted tests on a miniature turbojet engine powered by a Jet A-1 fuel with 10% of n-butanol. The authors showed that the performance parameters and emission characteristics for Jet A-1/butanol blend are comparable to those for neat conventional jet fuel.

The use of alcohol as a component for conventional fuel was discussed in the article [8]. Its direct application in aviation turbine fuel for supplying aviation turbine engines is, however, very limited, due to the failure to meet the requirements set by Aviation Fuel Quality Requirements For Jointly Operated Systems (AFQRJOS) [3]. However, butanol can be treated as semifinished material for synthesizing of biohydrocarbons. This fuel may be used in aviation high-pressure common rail injection systems [23], as well as an alternative energy source for many other transport sectors [5, 16, 20].

The team conducting the tests presented in this article has already performed numerous studies in the field of alternative fuels for use in gas turbine engines [9, 11, 12]. The tests concerning the impact of exhaust gasses emission on living cells (toxicity evaluation) is an interesting issue [13, 17].

This study aims to evaluate the effect of adding 2-ethylhexanol to jet fuel on the performance and combustion characteristics of a miniature turbojet engine Due to the complexity and expensiveness of the full-scale engine tests, the application of small-scale engines is an interesting solution. The blends results were compared with the results obtained for neat Jet A-1 fuel in terms of different engine operating modes, according to authorial methodology.

2. Methodology

2.1. Test rig description

Test stand studies were conducted on a laboratory test rig – MiniJETRig (Miniature Jet Engine Test Rig), which was constructed especially for the need of research-development works, in the scope of testing alternative aviation fuels mainly. An essential element of the rig is a miniature turbojet engine of the GTM 140 series. A detailed description of the test rig features and its individual elements is presented in [14], whereas the data regarding the technical specification of the miniature turbojet engine and used sensors were described in [11, 14]. The test rig, depending on the defined objectives and research needs, may have various configurations. This article focuses on engine operating parameters and measuring the emissions of gaseous components of exhausts. A schematic description of the test rig is shown in Fig. 1.

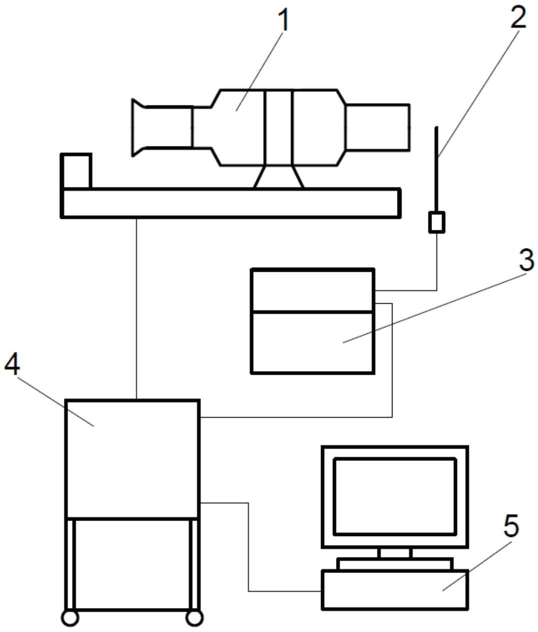


Fig. 1. Schematic diagram of experimental facility (1 – miniature jet engine, 2 – probe of analyser, 3 – portable exhaust analyser, 4 – measurement cards, 5 – computer with LabView application

In the course of the studies, engine was started up pneumatically, with the use of compressed air and a straight duct was used as the exhaust system. Such solution allows to measure the mass flow rate on the engine inlet. However, due to high temperatures in the combustion chamber, there was a need for the use of a straight duct in the exhaust system. The test rig has a distribution fuel supply system, consisting of two sub-systems. The main sub-system supplies tested fuel to the combustion chamber, while an auxiliary sub-system supplies a fuel with an admixture of oil onto the bearings, in order to insure their proper lubrication. This solution eliminates the adverse impact of oil on the assessment of a combustion process.

An emission analyser measurement probe was placed perpendicular to the outflow direction of exhaust gases, in the central stream and at a distance of not more than 0.5 of the exit nozzle diameter from the exit plane (according to ARP 1256D [22]).

2.2. Test fuels

Conventional jet fuel (Jet A-1) obtained via the Merox process and its blend with a 10% of 2-ethylhexanol were used in the tests. The above-mentioned blend was designated in the paper as 2-EH fuel. The blend with 2-ethylexanol was produced within the framework of an international EuroBioRef project. The goal of the EuroBioRef project was to find molecules, processed from raw non-food bio-material, that are compliant with the Jet A-1 fuel standards, that exhibit combustion characteristics as close as possible to those of the conventional fuel. The developed blend of Jet A-1 (90%) with 2-ethylexanol (10%) was indicated as a potential candidate for the process of certifying and approving new fuels for aviation turbojet engines [10].

The Tab. 1 shows selected physicochemical parameters of tested fuels. The properties were measured at the certified laboratory of Air Force Institute of Technology.

Tab. 1. Properties of tested fuels

Property	Test method	Limits	Results	
		AFQRJOS	Jet A-1	2-EH fuel
Density in 15 ºC, kg/m^3	ASTM D 4052	775.0 – 840.0	788.0	796.1
Viscosity in -20 ºC, mm^2/s	ASTM D 445	max 8.000	2.992	3.815
Heat of combustion, MJ/kg	ASTM D 3338	min. 42.80	43.300	43.280
Smoke Point, mm	ASTM D 1322	min. 18	25	28
Aromatics, % v/v	ASTM D 1319	max 25.0	15.8	12.7
Naphthalenes, % vol.	ASTM D 1840	max 3,0	0.40	0.32

Both samples of the tested fuels meet the requirements in the scope of selected properties. The 2-EH fuel is characterised by a slightly higher density and lower calorific value compared to the Jet A-1 fuel. The process of developing a fuel-air mixture and the combustion process in the engine in this case, will be mostly impacted by the viscosity. Adding 2-ethylhexanol clearly caused an increase of this parameter by ca. 27%, which may result in the formation of large size droplets when spraying fuel in the combustion chamber.

2.3. Procedure and test conditions

Engine tests were conducted according to a methodology presented in [15]. Experiment was repeated for each fuel twice. The parameters measured during each individual run were averaged for the last 30 seconds in that engine operating state. Such an adopted assumption guaranteed obtaining stable values for all measured parameters (low standard deviation values). Next, a given parameter was averaged based on the results obtained from two independent tests conducted for a specified fuel. The figures presented in the following chapter, apart from an average value of an individual parameter in a specific engine operating state, also have its maximum and minimum values, which correspond the average value from individual engine tests. The data presented in such a way indicate the repeatability of the obtained measurement results according to the adopted methodology and provide a base for the performance of a fuel comparative analysis.

Due to the fact that ambient conditions impact engine performance, as well as the course of the combustion process, all engine tests were conducted on the same day. Such an approach creates a possibility of performing tests in similar ambient conditions (Tab. 2).

Tab. 2. Ambient test conditions

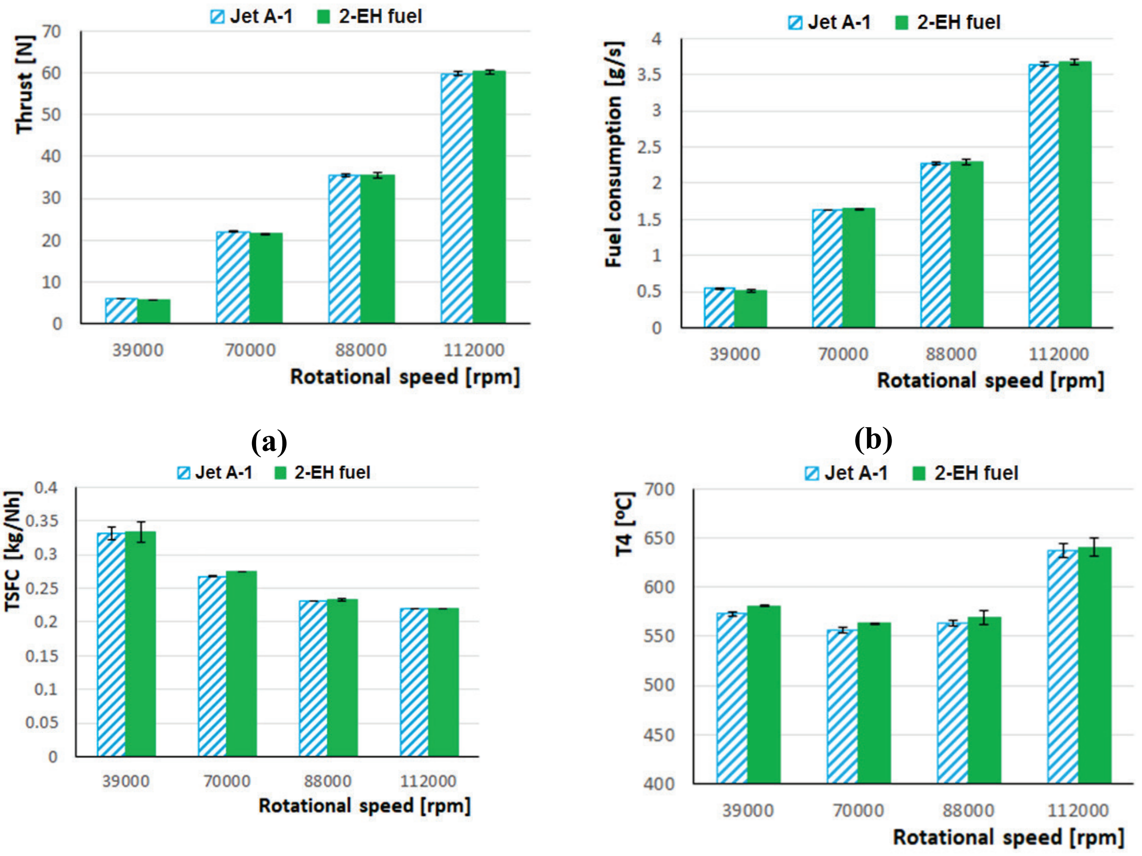
Fuel	Test No.	P_o (bar)	T_o (°C)	RH (%)
Jet A-1	Test 1	1000.5	21.1	52.0
	Test 2	1000.3	22.2	46.6
2-EH fuel	Test 1	1000.4	23.3	43.1
	Test 2	-	-	-

3. Results and discussion

3.1. Engine performance characteristics

Comparative results for the tested fuels: Jet A-1 and 2-EH fuel, in terms of their impact on the main engine operating parameters: thrust, fuel flow, thrust specific fuel consumption and turbine temperature were presented in Fig. 2.

Based on the following results, it can be concluded that no significant differences in the operation of a miniature turbojet engine supplied with the 2-EH fuel were obtained, compared to the operation using neat Jet A-1. Similar values of selected parameters were obtained in all tested engine operating states.



(a) (b)

(c) (d)

Fig. 2. Selected engine parameters as a function of rotational speed (a) Thrust, (b) Fuel consumption, (c) Thrust specific fuel consumption, (d) Turbine inlet temperature

Figure 3 shows relative changes of the following parameters: thrust, fuel consumption (converted to g/s) and thrust specific fuel consumption. These changes concern the results obtained for the 2-EH fuel, related to the results for the Jet A-1. The analysis of the engine operation at a speed of 39 000 rpm was omitted due to the fact that this low state of engine operation is characterized by large measurement difficulties. Low values of the measured parameters and, hence, the operation of sensors in their low operation ranges may be the cause for obtaining results encumbered with a higher measurement error.

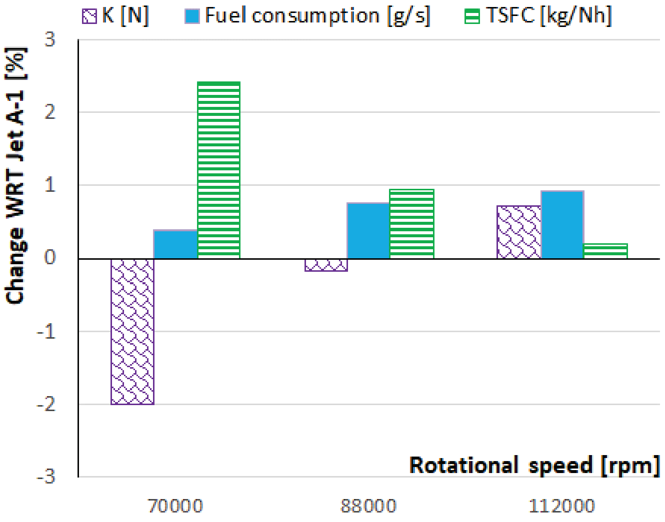


Fig. 3. Relative changes of selected engine parameters between different test fuels

The differences in thrust, fuel consumption and thrust specific fuel consumption between the tested fuels do not exceed 3% on all analysed engine operation states. Fuel consumption and thrust specific fuel consumption is slightly higher for the 2-EH fuel compared to the Jet A-1.

3.2. Emission

Figure 4 shows comparative results of the tested fuels in the scope of generated emissions of the following combustion process components: CO, CO_2 and NO_x. The data for gaseous components was converted according to specified rules from ppm (or %) to emission indices expressed in g/kg of fuel.

In the case of CO and CO_2 emission, similar results for both tested fuels in all analysed engine operating states were obtained. Only for NO_x, the index values obtained for the 2-EH fuel were higher than for Jet A-1. However, it should be noted that during the tests on a miniature turbojet engine, were low NO_x concentration values were obtained, and the differences between fuels in a given engine operating state remained at the level of a measurement error (max ± 5ppm).

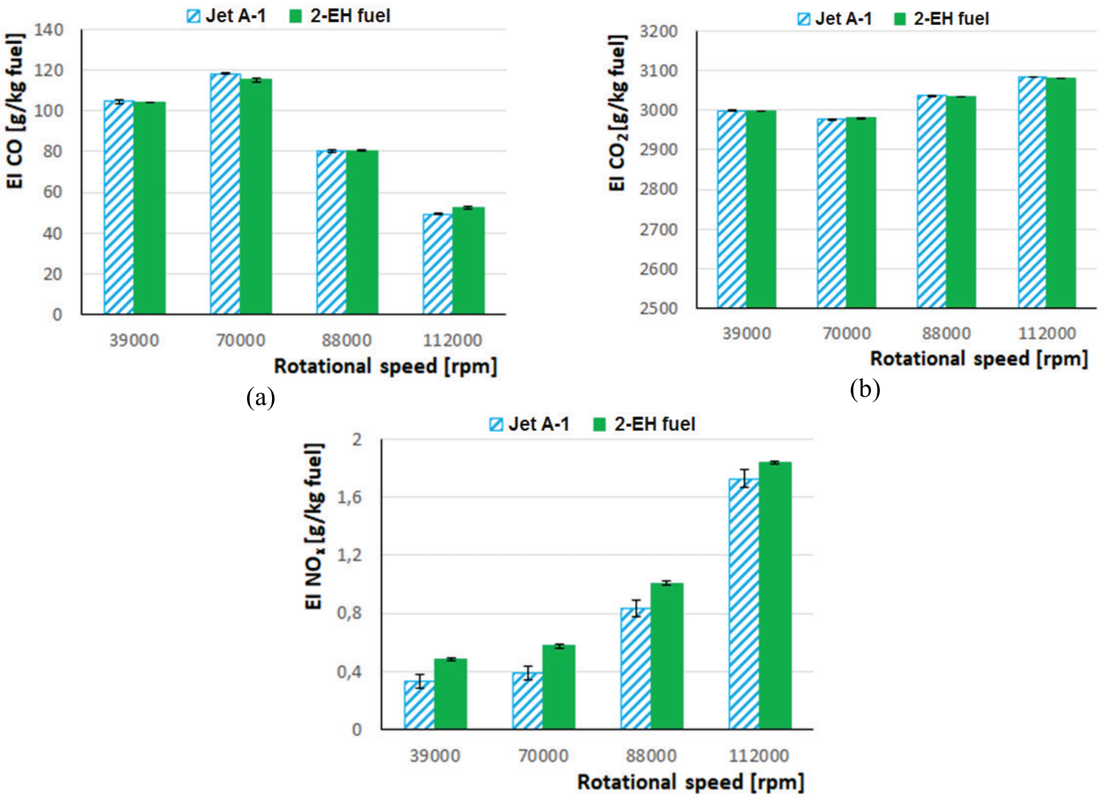
For this reason, Fig. 5 shows only relative changes between the fuels in the scope of CO and CO_2 emission index changes. In the case of CO emission, the obtained changes between the tested fuels do not exceed 3% (with the exception of the speed of 112 000 rpm). For the speed of 112 000 rpm, the calculated CO emission index for the 2-EH fuel is ca. 6% higher in relation to the Jet A-1. The differences between the CO_2 emission index of the tested fuels are negligible (do not exceed 0.5%).

4. Conclusions

The performance and emissions parameters of a miniature turbojet engine fuelled with Jet A-1 and 2-Etylohexanol blend were investigated and compared with neat Jet A-1. It was shown that adding 2-ethylhexanol to jet fuel changes the physico-chemical properties of the obtained blend, mainly in viscosity. The results from engine tests are summarized as follows:

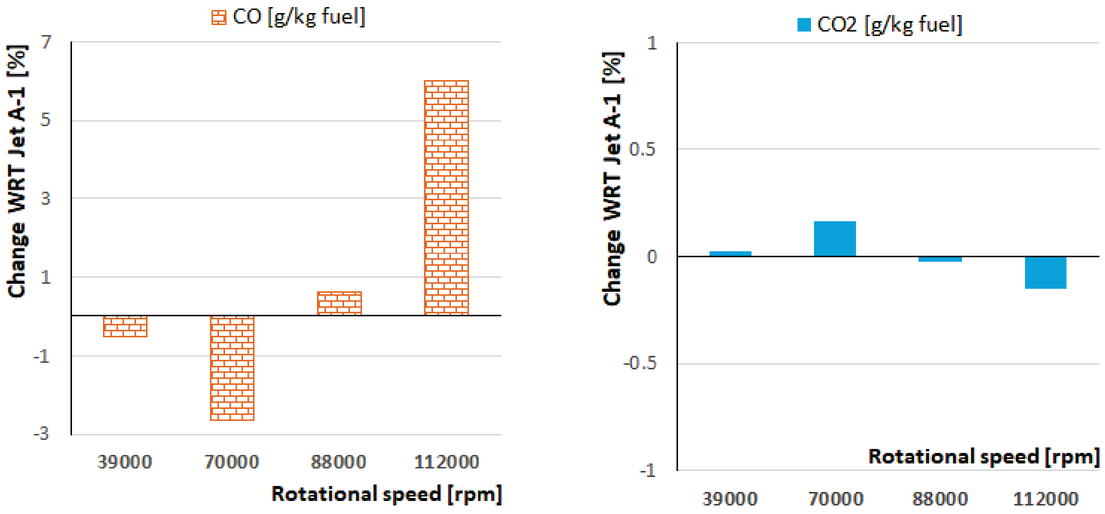
- the obtained differences in the scope of thrust, fuel consumption and thrust specific fuel consumption values between the tested fuels are negligible – not exceeding 3%,
- the parameter values of fuel consumption and thrust specific fuel consumption are slightly higher for the 2-EH fuel compared to Jet A-1,

- in the case of CO_2 emission, similar results for both tested fuels in all analysed engine operating states were obtained (the differences do not exceed 0.5%),
- in the case of CO emission, the differences between the tested fuels do not exceed 3% (with the exception of the speed of 112 000 rpm). For this speed, the calculated CO emission index if higher by ca. 6% for the 2-EH fuel compared to Jet A-1,
- in the case of NO_x emission, higher values of this index were obtained for the 2-EH fuel than for the Jet A-1. However, in the course of the conducted engine tests, the range of measured NO_x concentrations was several ppm, hence, the presented results may be subject to large uncertainty.



(a) (b) (c)

Fig. 4. Exhaust gas emissions as a function of rotational speed. (a) EI CO, (b) EI CO_2, (c) EI NO_x



(a) (b)

Fig. 5. Relative changes of emission indices between the tested fuels. (a) CO, (b) CO_2

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