Modification of aviation gasoline with aliphatic alcohols additives: an analytical review of prospects

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Abstract: The paper presents the results of analysis of the regulations of the traditional aviation fuels quality. The content of antiknock additives in these fuels has been established in the investigated fuels. The influence of aliphatic alcohols on operational, physical and chemical and environmental properties of traditional petroleum aviation fuels has been studied. The research has also investigated the use of ethyl, methyl and butyl alcohols in motor-car fuel systems in the composition of complex and pure alternative fuels in aviation. It has been confirmed that addition of aliphatic alcohols to traditional aviation fuels enables reduction of harmful emissions in the upper layers of the atmosphere. Alcohol-containing petrol is being enriched with oxygen, which enables more complete combustion of fuel and lessens emissions of carbon oxides.

Keywords: fuel; oxygenates; aliphatic alcohols; bioethanol; biomethanol; biobutanol.

Reference to this paper should be made as follows: Boichenko, S., Lejda, K., Lychmanenko, O., Boichenko, M. and Reshetilowski, V. (2015) 'Modification of aviation gasoline with aliphatic alcohols additives: an analytical review of prospects', *Int. J. Sustainable Aviation*, Vol. 1, No. 4, pp.324–332.

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This paper is a revised and expanded version of a paper entitled 'Aviation gasoline with the addition of aliphatic alcohols' presented at the International Symposium on Sustainable Aviation (ISSA-2015), Istanbul, Turkey, 31 May to 3 June 2015.

1 Introduction

Under growing consumption of high-quality petrochemicals the question of improvement of efficiency and environmental safety of aircrafts, in particular, those with piston engines, economy and rational use of aviation fuels is gaining great importance.

The considerable disadvantage of the well known brands of aviation petrol is the presence of efficient, but very toxic antiknock additive – tetra-ethyl lead (TEL). Having analysed the provisions of ГОСТ 1012, ТУ 38.401-58-47-92, ТУ 38.101913-82, DEF STAN 91-90 issue and ASTM D 6227, we have developed the comparative Table 1 about the content of TEL in composition of aviation petrol. The table visualises the tendency for diminishing of TEL content in composition aviation petrol, however almost all brands of fuels contain toxic TEL today. We have formulated a hypothesis – to provide the improvement of aviation petrol environmental safety with modification of aviation petrol composition by introducing oxygenates, for example, aliphatic alcohols, to substitute toxic TEL.

Nowadays many countries are actively developing the programs of biopropellants introduction, mainly through their introduction into the composition of traditional oil fuel. According to the modern requirements of European Union (EU) according to the directive ES 2009/28/EU the share of renewable energy in general balance of energy consumption should attain 20% and biopropellants – at least 10% by 2020.

Table 1 Content of TEL in aviation petrol

№	*Aviation petrol brand*	*Regulation*	*Content of antiknock agents*	*Name of antiknock agents*
1	2	3	4	5
1	Б-95/130	ГОСТ 1012-72	3.1 g/kg	TEL
2	Б-91/115		2.5 g/kg	
3	Б-92	ТУ 38.401-58-47-92	2.0 g/kg	
4	Б-70	ТУ 38.101913-82	0	
5	Avgas 80	DEF STAN 91-90 Issue 3	0.14 g/l	
6	Avgas 100LL		0.56 g/l	
7	Avgas 100		0.85 g/l	
8	82UL	ASTM D6227	0	Similar to automobile gasoline but without automotive additives
9	85UL	-	0	Oxygenate-free
10	91/96	-	Almost negligible	TEL
11	91/96UL	ASTM D7547	0	Ethanol-free, antioxidant and antistatic additives
12	100/130	-	1.12	TEL
13	G100UL	-	0	Aromatic compounds such as xylene ormesitylene
14	100SF	-	0	Mesitylene
15	115/145 (‘Avgas 115’)	-	1.29	TEL

The International Civil Aviation Organization (ICAO) has by now defined 300 initiatives for the production and use of alternative types of fuel. Five large consortia to work in the field of alternative types of fuel for aviation have been created for today. The world tendency shows that commercial trips which use the alternative types of fuel have already become more than a concept.

According to the agreement about the environmental policy, approved at the 38th ICAO Assembly (2013), the world market instruments allowing the reduction of CO_2 emissions to the minimum from 2020 must be developed. One of the priority instruments for the solution of this task is introduction of alternative fuels, which decrease the volume of CO_2 by 50% by 2050 (comparing to 2005). The International Association of Air Transport (IATA) has planned the reduction of CO_2 emission by 30% by 2025.

The authorities in the field of civil aviation airworthiness determine the safety of aircrafts exploitation on the basis of specifications on aviation fuel.

1.1 Problem formulation

The research on the use of aliphatic alcohols as additives to aviation petrol for the improvement of physical and chemical, operating and environmental properties is currently being conducted in the whole world and confirms the prospects of traditional fuels modification with oxygenates (primarily, biomethanol, bioethanol, and biobutanol).

- *purpose:* substantiate the prospects of TEL substitution with oxygenate additions in composition of aviation petrol
- *research object:* modification of aviation petrol composition with the additions of aliphatic alcohols
- *research subject:* physical and chemical properties of aviation petrol and prospects of TEL replacement with complex of oxygenates.

2 Literature overview

The analysis of existing literature (Vdovin and Bondarenko, 2014) has led to the conclusion that addition of aliphatic alcohols into the composition of fuel changes their property. Thus, the combustion heat of ethanol, methanol, and butanol is substantially lower than that of aviation petrol, which leads to the increase of fuel consumption during the application of these alcohols. However, the content of oxygen in composition of oxygenates, results in higher efficiency of fuel combustion, therefore this difference in combustion heat becomes not so important.

Emission of products of incomplete combustion decreases and formation of soot diminishes under the condition of alcohols use. However, emissions of aldehydes (as the product of incomplete oxidation of alcohols) are growing, also there is potential for increased emissions of nitrogen oxides. In addition, alcohols are hygroscopic, have low lubricating characteristics, are corrosive-aggressive, and negatively influence construction materials.

The main disadvantage of petrol-alcoholic fuels is their phase instability, conditioned by the presence of water in their composition and, as a result, limited mutual solubility of components. This is successfully solved by the introduction of the proper modifiers and stabilisers into the alcoholic fuels.

The efficient stabilisers for petrol-alcohol mixtures are suggested to be aliphatic alcohols of C3–C12 of normal and branched structure, phenols, alkylacetates, ethers and esters and their metalorganic derivatives, ketones, amines, surfactants, glycols and their ethers, aldehydes, ketals, acetals, alkylcarbonates, hydrocarboxylic acids and mixtures of these compounds.

The most widespread type of biopropellant is bioethanol, its share in the world production of fuel from biological raw material is 82%. The leading producers are the USA and Brazil (Asyaev et al., 2010).

As the use of aliphatic alcohols, such as methanol, ethanol and butanol, as additions to motor-car petrol, is highlighted in the literature, the further discussion will deal with the prospects of aviation petrol modification with these oxygenates, as well as with properties of these additives.

2.1 Methanol

Methanol is one of widely used types of fuel, as it has high antiknock value (Onoychenko, 2000). The most widely used motor car fuel mixtures are M85 (85% methanol and 15% hydrocarbons) and pure methanol M100 (100% methanol) (Lotko et al., 2000). In all cases it enables reduction of exhaust gases toxicity. Application of 100% methanol is limited owing to its toxicity and corrosive aggressiveness in relation to construction materials, which results in the reduction of engine durability, worsening fuel quality, and increasing organic volatiles emission, which can result in ozone concentration reduction. Methanol is also characterised by high emissions of formaldehyde, while ethanol combustion produces mainly acetic aldehyde (Karpov et al., 2006).

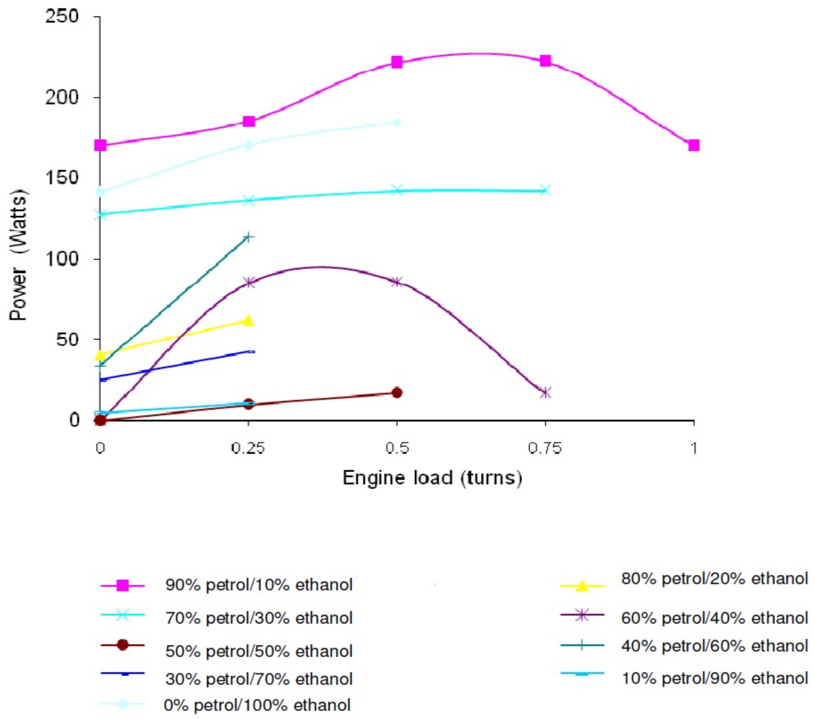
Operating properties, power indexes and starting properties of methanol fuel are improved after the additional introduction of higher alcohols and ethers. Such fuels have got the name of mixed alcoholic fuels. The tests (Bondarenko et al., 2011) of one of fuel blend compositions have showed increased engine power by 4–7%, improvement of fuel economy (as compared to pure alcohol) by 10–15%, and decreased content of oxides of nitrogen in exhaust gases by 25–30% as compared to work on petrol.

The highest interest in the use of methanol as a fuel is observed in countries that have their own resources of anthracite coal and insufficient resources of oil. Methanol can be made from natural gas, coal, and biomass.

2.2 Ethanol

Ethanol as fuel additive is much more interesting, as it is better soluble in hydrocarbons and less hygroscopic.

Figure 1 Variation of engine power with various loads for different qualities of ethanol gasoline blended fuel (see online version for colours)



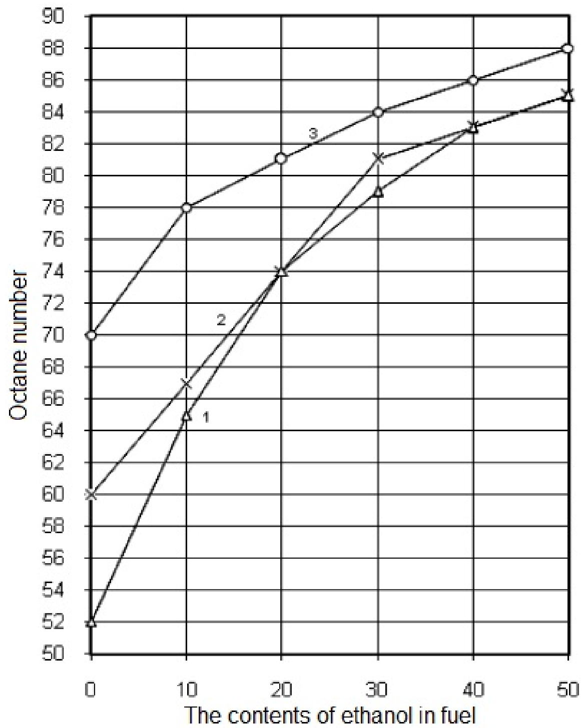
Source: Tangka et al. (2011)

Petrol with the addition of 10% ethanol is enriched with oxygen, which contributes to complete combustion and diminishing of carbon oxide emissions by 30%. Also it diminishes total emissions of toxic matters (Ablaev, 2009) by 30% and emissions of volatile organic compounds by more than 25 %. The use of this petrol and ethanol mixture prevents engine overheating, plays the role of antifreeze for the fuel system and does not cause contamination of fuel injectors.

The value of efficiency factor for alcoholic engine is higher than that of petrol in the range of all working mixtures; therefore the specific energy consumption per unit of power is lower. General efficiency of fuel gradually grows with the increase of percent content of ethanol in fuel (Polunkyn et al., 2012).

In real conditions petrol-alcohol fuel inevitably absorbs water in the process of storage, transportation and exploitation, which results in phase division. This problem of petrol-alcohol mixtures is not eliminated even with use of absolute alcohols. The possible stabiliser is furancarbinol (Gaidai et al., 2011).

Figure 2 Ethanol affects the formation of octane number gasoline



Notes: 1 – gasoline yshymbayskyy; 2 – Б-59; 3 – Б-70.

Source: Bogdanov et al. (2008)

2.3 Butanol

The use of biobutanol is the next important stage of biopropellants development, but its application must satisfy growing requirements for environmentally safe, renewable transport fuel (Vnukova and Barun, 2011).

Butanol produces more net energy per working cycle than ethanol or methanol, and approximately by 10% more than petrol.

Biobutanol provides considerable environmental advantages as compared to oil-based fuels, including the lower level of emissions of exhaust gases. Biobutanol (Imankulov, 2010) also enables limiting and, possibly, reducing the level of carbon dioxide emissions.

The mixture, which contains biobutanol, with the presence of water, is less inclined to stratification, than the mixture of ethanol/petrol, and therefore it is possible to use the existing infrastructure of distribution without modifications of mixing installations, deposits or refuellers.

Important advantages of biobutanol are also high combustion heat in relation to bioethanol, which enables the use of higher biobutanol concentration in petrol. In addition, it can be produced from inedible products, which is an efficient method of using agricultural and timber processing wastes utilisation.

Butanol is safer in application, as its evaporability is six times lower than what is typical for ethanol and 13.5 times lower than for petrol (Imankulov, 2010).

Butanol could be used as a substitute for petrol as a fuel to greater degree, as compared with ethanol, due to physical properties, economic efficiency, safety, and also because its use does not require engine modification. The principal reason for low awareness about butanol as an alternative fuel is that the production of this alcohol has never been considered efficient.

3 Conclusions

The analysis of literary sources has shown that presently the issues of production and adjusting properties of alcohol-containing aviation petrol have been widely considered in scientific researches. In particular, the aviation petrol, developed in USA and produced in accordance with the standard ASTM D 6227, does not contain TEL, but its testing is not completed yet.

Currently attention is paid to the development of aviation petrol with content of ethanol, as it is the aliphatic alcohol that is produced in the biggest volumes. Ethanol is also the most applicable due to its hypotoxicity. As compared with methanol it is less corrosion aggressive and hygroscopic, and more soluble in hydrocarbons. Ethanol petrol is enriched with oxygen and its combustion is more complete.

Nowadays the additive among aliphatic alcohols with the best prospects is biobutanol. As it was found out during the analysis of literature, it is the least aggressive to engine components, it provides the most stabilising influence for alcohol-petrol mixtures, it increases antiknock characteristics and it reduces the amount of toxic emissions.

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