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BUTANOL/BIOBUTANOL AS A COMPONENT OF AN AVIATION AND DIESEL FUEL

Wojciech Dzięgielewski, Bartosz Gawron, Urszula Kaźmierczak, Andrzej Kulczycki

Air Force Institute of Technology
Księcia Bolesława Street 6, 01-494 Warszawa, Poland
tel./fax: +48 22 6851055
e-mail: wojciech.dziegielewski@itwl.pl;bartosz.gawron@itwl.pl
urszula.kazmierczak@itwl.pl;andrzej.kulczycki@itwl.pl

Abstract

This paper describes the analysis and conclusions regarding the use of butanol/biobutanol as a component of conventional mineral fuels employed in different areas of transportation. Butanol from biomass – biobutanol is interesting as biocomponent of gasoline, diesel fuel as well as aviation fuels. This is especially important in case of air transport, which is the carbon dioxide emission source of the fastest growth. Biobutanol is tested as biocomponent of gasoline, including aviation ones, but there are no information about biobutanol added to mineral Jet fuel as well as diesel fuel. Direction of research conducted by leading aviation companies indicates that hydrocarbon biocomponent will be main biofuel used as aviation turbine fuel. One of reported technology is focused on use of butane-1-ol as semi-finished products for isoparaffinic hydrocarbons generation that then would be used for aviation turbine fuels production. In order to do such analysis the preliminary lab testing of blends of butanol isomers with aviation fuel Jet A-1 and diesel fuel were performed. The paper contains the results of standard tests for blends of mineral fuels with butane-1-ol and butane-2-ol added in concentration of 0-20 %(V/V). Both the advantages and disadvantages regarding the use of such component of mineral fuels are presented. Butanol decreases value of flash point and significantly influence on conductivity of Jet fuel. In case of aviation fuel for turbine engines, and diesel fuel, the restrictions regarding direct use of butanol are important. However, butanol can be treated as semi-finished material for synthesizing of biohydrocarbons used in above applications.

***Keywords**: aviation and diesel fuels, biocomponents, CO_2 emission*

1. Introduction

Use of biocomponents as substitute for petroleum fuels is important part of energy policy, both all over the EU and in individual member countries. Increasing demand for fuels and energy connected with economy growth, due to decreasing sources of fossil fuels, means searching and supporting the use of biocomponents, liquid biofuels and other renewable fuels. Biocomponents contribution in total sum of consumed fuels, computed in relation to calorific value, shall increase successively up to 10% in 2020 [7].

The importance of biocomponents is highlighted mostly on account of such aspects as ecology (environment protection), economy (increase and big fluctuations of crude oil price), public matters (increase a demand for agricultural raw materials resulting in development of agriculture and rural regions), and energy safety (intention to gain energy independence of countries rich in crude oil). One of major merits supporting the use of biocomponents and biofuels in different fields of transportation is possibility to limit CO_2 emission [8]. This is especially important in case of air transport, which is the carbon dioxide emission source of the fastest growth. Because of this, since 2012, the European aviation sector has been included in emissions trade system, aimed at limiting harmful exhaust gases emission. Equally important aspect of biocomponents use is possibility to influence on environment through limiting undesirable things, thanks to use of by-product residues from other processes (e. g. from producing „traditional" biocomponents – bioethanol, FAME) [2]. Such an example is obtaining butanol isomers from fusel oil residue after bioethanol fermentation.

Current condition of science and technology allows to produce on large (industrial) scale only biofuels of 1st generation (i.e. bioethanol and FAME), that is, from food agricultural materials (mostly grains, sugar cane and vegetable oils). Biobutanol can be produced from different biomass materials, including no-food ones, so we can recognize it as biofuel of II generation. The development and spreading the methods of production of higher generation biofuels, incl. biobutanol, is being estimated for the closest years, so there is increasing interest in this biocomponent.

2. Butanol/biobutanol as a component of mineral fuels in different applications

Higher-order alcohols, incl. butanol, arouse special interest because of the role they would play in the future [1, 2]. Petrochemical industry employs alcohols, mostly the ethanol, as automotive gasoline components. However, the researches indicate that use of butanol is more favourable than use of ethanol. The butanol calorific value of 29.2 MJ/dm^3 is considerably higher. Moreover, butanol has relatively low heat of vaporization, and is less corrosive than ethanol. Currently, butanol is used only in limited range, but the extensive research work focused on expanding the use of biobutanol as gasoline component are under progress [2, 3, 5, 9].

Tab. 1. Comparison of energy values of butanol and other fuels

Fuel	Calorific value [MJ/l]	Heat of evaporation [MJ/kg]	RON	MON
Gasoline	32	0.36	91-99	81-89
Butanol	29.2	0.43	96	78
Ethanol	19.6	0.92	130	96
Methanol	16	1.2	136	104

The ASTM D7862, specification for blend of gasoline and butanol at the level 1 to 12.5%, as a fuel for automotive SI engines, has been published in October 2013. The specification covers three isomers of butanol: butane-1-ol, butane-2-ol, and methylpropane-1-ol. The 2-methylpropane-2-ol (TBA – tert-butyl alcohol) is evidently excluded. Use of biobutanol as gasoline biocomponent gives notable benefits to environment:

- according to calculations performed by DuPont and BP, the GHG emission in Well-to-Wheel biobutanol chain, in case of same raw materials, is not higher than for bioethanol,
- thanks to the low vapour pressure of biobutanol, (lower than for gasoline) the use of biobutanol, as gasoline biocomponent does not pose the risk of volatile organic compounds emission increase.

Biobutanol has been tested also in regard to its use in CI engines. The research conducted by Wroclaw Technical University [10] at engine test bench proved that traditional CI engines, without any conversions, would be fuelled with blend of butyl alcohol and rapeseed oil.

The aircraft industry currently also works on alternative fuels. The most important fuel for aircraft operation is the aviation turbine fuel. This fuel is used in prevailing amount of aircrafts and helicopters.

Current fuels used in aviation reciprocating engines include compounds of sulphur, lead and bromine. According to Chicago Convention, standardisation and application of these fuels relates to aviation reciprocating engines driving aircrafts of General Aviation (GA) class in all countries – members of International Civil Aviation Organisation. According to EPA report, the annual consumption of Avgas fuel in United States has been maintained at the level of 600 to 1000 million litres since 2000 that means the emission of lead at the level of 500 to 800 tons. There were 200 000 planes with reciprocating engines in use in the United States over the year of 2008.

They consumed 235 326 00 US gallons of avgas 100 LL. One gallon of such fuel contains 2.12 g of lead. So the lead emission was 522 tons. Similar situation is in Europe. The 6% increase of GA planes amount all over the world means continuous demand for aviation gasoline, potentially dangerous for environment because of content of lead and bromine compounds, and sulphur oxides. It seems necessary, and inevitable to replace the Avgas fuel with alternative fuel that does not contain compounds harmful to environment. One of the core candidates is biobutanol. It is more appropriate for aviation than ethanol [14], although its octane numbers are lower. It is possible to use post-fermentation butanol isomers as supplementary component, and not as just the only one.

Direction of research conducted by leading aviation companies indicates that hydrocarbon biocomponents will be main biofuel used as aviation turbine fuel [15]. In face of such trend, there are no literature reports about use of biobutanol as biocomponent of these fuels. But there is work on technology focused on use of butane-1-ol as semi-finished products for isoparaffinic hydrocarbons generation that then would be used for aviation turbine fuels production. The technology path, recognized by different companies, incl. Gevo, is the following.

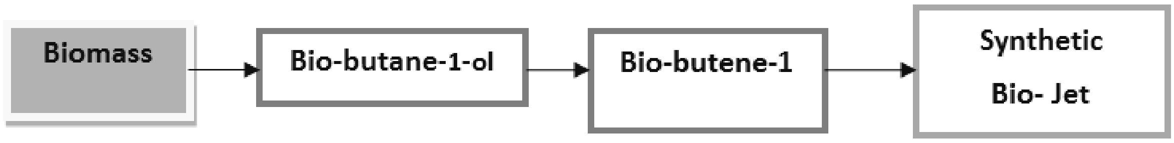


Fig. 1. Example of technology path to receive synthetic Bio-Jet

According to the issue analysis, we can see that essential problem, and biobutanol including fuels development barrier is technology for such biocomponent production [3, 4, 9, 14-13]. The productivity of known technologies, based on fermentation process, is too low. Hence, the strong emphasis is put on modification on existing, and development new technologies of biobutanol production from available vegetable raw materials. But, there is another way – more favourable, esp. to environment, and also very valuable for industry. It is possible to obtain butanol isomers from bioethanol production residue. Besides fuel component obtaining, the waste material would be reclaimed.

3. Testing the physical and chemical properties of butanol and mineral fuel blends

Increasing interest in biobutanol as an component of automotive and aviation fuels inclined the Air Force Institute of Technology to take preliminary research on possible use of butanol as component of above-mentioned fuels. The research covered two butanol isomers: butane-1-ol and butane-2-ol as components of biobutanol. At this level of work, it has decided to use components of reagent type, not from fermentation process. Thanks this the interferences from post-production fractions contamination have been avoided. The work was also restricted to make blends of every isomer with Jet A-1 fuel and diesel fuel. The testing covered commercially available Jet A-1, and diesel fuel without FAME. The blends included from five to 20% (V/V) of butane-1-ol, and butane 2-ol. Because of significant differences in operational characteristics, the aviation gasoline has not been used. This is separate, extensive issue.

Mineral fuels and blends have been tested according to standard requirements for Jet A-1 and diesel fuel. Selected test results have been summarized below. The essential direction results analysis covered parameters the most important in regard to fuel and drive systems utilisation process, and at the same time, the most prone to changes caused by introducing the butanol into mineral fuel.

Change of selected properties of blend of aviation fuel Jet A-1 and butane-1-ol and butane-2-ol – see Fig. 2-5.

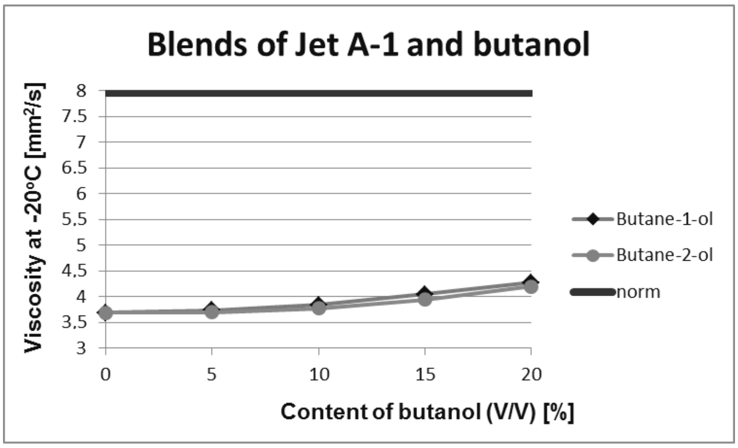


Fig. 2. Influence of butanol content in Jet A-1 on kinematic viscosity at -20°C

Increase of butane-1-ol, and butane-2-ol content results in kinematic viscosity at -20°C increase (Fig. 2), proportionally to increase of butanol content in aviation fuel. There have been no significant differences regarding effect of butane-1-ol and butane-2-ol on value of this parameter.

The calorific value of blends (Fig. 3) decreases compared to neat aviation fuel. Calorific value lowering, however, is not proportional to butanol content in the range of 0-20% (V/V) and is different for butane-1-ol and butane-2-ol.

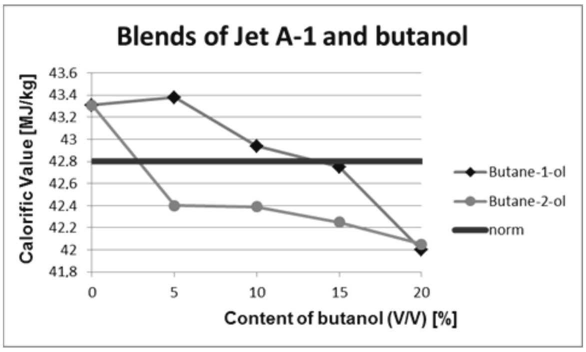


Fig. 3. Influence of butanol content in Jet A-1 on calorific value

As a polar compound, butanol negatively influences on fuel conductivity (Fig. 4). This is particularly noticeable in case of butane-1-ol which gives in-spec. results at concentrations from 0 to 10% (V/V) whereas conformity with specifications in case of butane-2-ol is maintained at concentration up to 15% (V/V). Addition of butane-1-ol and butane-2-ol to Jet A-1 fuel results in wear scar diameter increase of the blend (Fig. 5). The more butanol concentration is the bigger scar diameter.

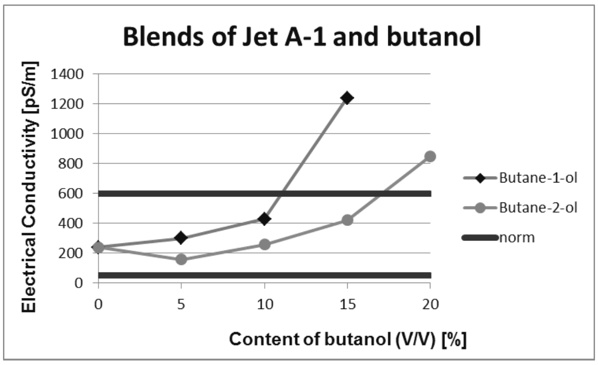


Fig. 4. Effect of butanol content in Jet A-1 on conductivity

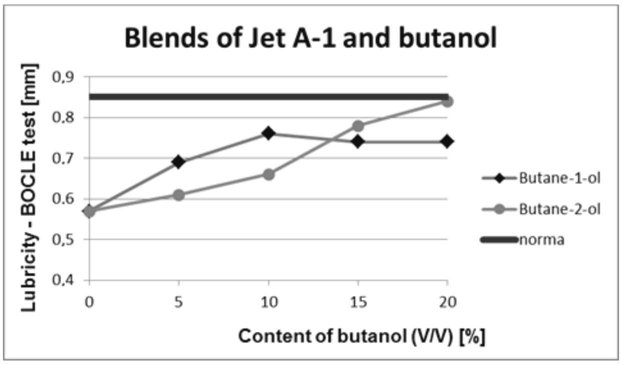


Fig. 5. Effect of butanol content on aviation fuel lubricity (BOCLE test)

The properties of diesel fuel and butanol blends are shown in Fig. 9-11.

Data in Fig. 6 indicate high hygroscopicity of butanol in blend with diesel fuel. This is especially distinct in case of butane-2-ol, where just at 10% (V/V) butanol concentration, the water content exceeded allowable level 200 ppm.

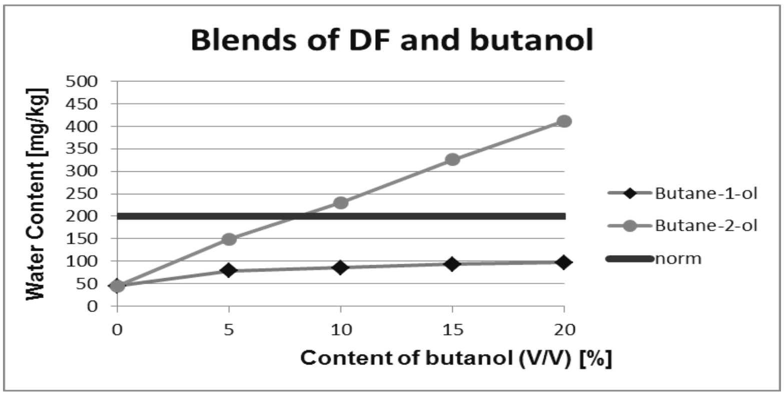


Fig. 6. Effect of butanol content in diesel fuel on water content in blend

The calorific value of diesel fuel with butane-1-ol, and butane-2-ol blends decreases in relation to neat mineral fuel (likewise in case of aviation fuel and butanol blends). Calorific values for diesel fuel and butanol blends change proportionally to alcohol content.

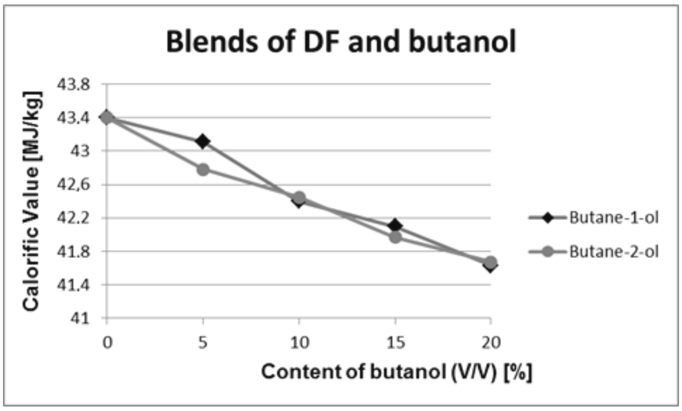


Fig. 7. Effect of butanol content on calorific value of blends

Butanol addition effects negatively on wear measured using HFRR test method.

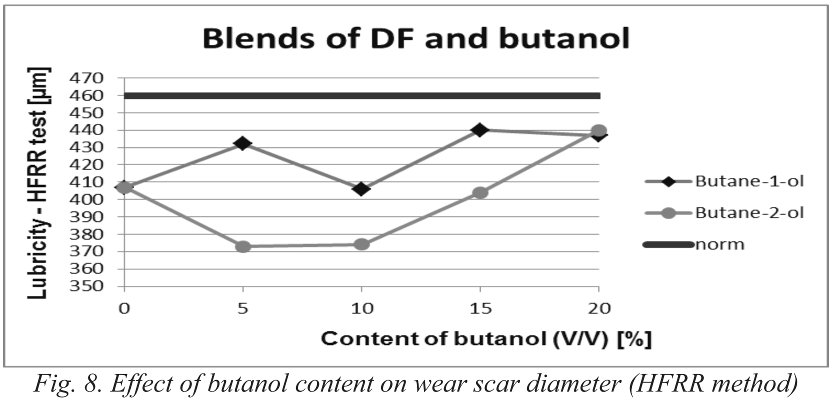
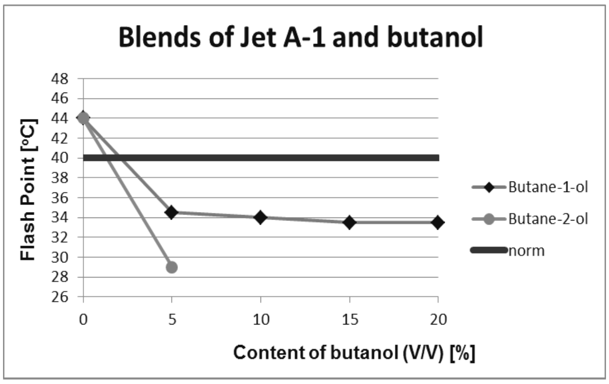


Fig. 8. Effect of butanol content on wear scar diameter (HFRR method)

Although all results (Fig. 8) fall into requirements for diesel fuel, but especially in case of butane-1-ol we can observe wear scar increase almost at whole range of concentrations. In case of butane-2-ol, and concentrations of 5 and 10% (V/V), the wear was lower in relation to neat diesel fuel, but further increase of butanol content causes gradual wear increase.

Basing on preliminary testing it is found that butanol addition has adverse impact on especially one of operation parameter of mineral fuels – the flash point. Just only 5% (V/V) of butanol content in Jet A-1 or in diesel fuel means that this parameter is distinctly under specification requirements.



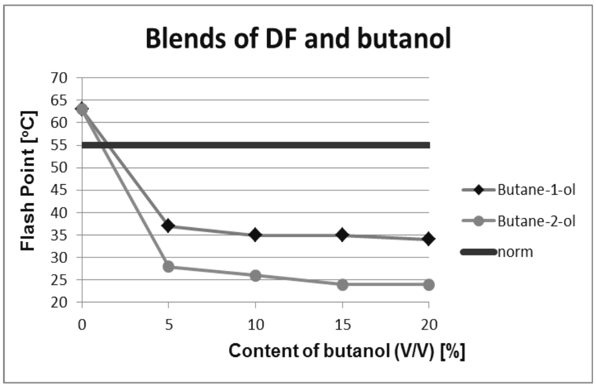


Fig. 9. Effect of butanol content in mineral fuel on flash point: a) Jet A-1 with butanol, b) diesel fuel with butanol

4. Conclusions

As a result of problem analysis and preliminary research regarding possible use of biobutanol as component of aviation fuel Jet A-1 as well as diesel fuel, it is recognize that this is the proper trend, currently being developed all over the world. First of all, the use of biobutanol as an alternative fuel allows to lower the CO_2 emission. According to available literature, we can see both the benefits of development of fuel containing biobutanol technology, and limiting the use of bioethanol.

Undoubtedly, the most favourable way of butanol/biobutanol use is gasoline, incl. the aviation one. Biobutanol does not have such negative characteristics of commonly used bioethanol as high vapour pressure or too high hygroscopicity.

In case of heavier fuels such as aviation turbine, and diesel ones, the restrictions regarding direct use of butanol are bigger than in case of gasoline. However, butanol can be treated as semi-finished material for synthesizing of biohydrocarbons used in above applications.

Restrictions regarding butanol use depend on its concentration in blend with mineral fuel. It has found that introducing the „optimum" amount of butanol into specific product. Basing on laboratory testing results regarding the properties of blends, and passing over restrictions connected with flash point, we can say that direct introduction of approx. 10% (V/V) of butane-1-ol into Jet A-1 and diesel fuel is acceptable.

The extended laboratory testing regarding biobutanol use as component of mineral fuels is currently in progress. It is expected to perform comparative bench testing using model turbine jet engine fuelled with traditional Jet A-1, and blend of Jet A-1 with specific type of butanol. It is expected that it would be possible to translate laboratory test results into effects obtained during real engine operation, and simultaneously to evaluate comprehensively the effect of butanol as fuel component.

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