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THE LIMITATION OF USE OF BIOCOMPONENTS IN THE FORM OF FATTY ACID METHYL ESTERS BASED ON ANALYSIS OF SELECTED TURBINE FUEL PROPERTIES

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Abstract

This paper describes part of results of research work consisting in testing the possibility to use biocomponents in fuels for turbine engines. Because of some similarity and availability as well as that this is the first stage of work, the fatty acid methyl esters (FAME) (from rapeseed oils) were used as the basis biocomponent. Up till now, this ester was used as component of fuel for compression engines. There is no proved information on other use of FAME. The aim of research work is to show possibilities or rather restrictions and risk in case of new application. Some behaviour of biofuels or biocomponents are known. The common virtue is perfect lubricity, and the flaw is chemical and thermal stability. But, these are not only parameters we should notice analysing the applicability. This paper also tries to show other properties, that could restrict the use. It presents biofuels laboratory test results and points the expected problems in case of practical use of such mixtures. The results would be base to engine bench testing.

Keywords: *transport, turbine engines, fuel, biocomponents, properties*

1. Introduction

There is no need to prove anybody that in recent times one of the most important, and publicized definitely thing is emission of various contaminants created during majority of fuels combustion process. Traditional source of energy necessary to power engines, to heat generation etc. are fossil fuels, mostly coal, crude oil and natural gas. Crude oil particularly is very troublesome raw material. Beside future problems regarding deposits mining and continuous rise of extracting cost, harmful effect of crude oil-based combustion products on environment is the second, very important aspect. Though more and more modern engine designs with better efficiency and restricted emissions, the range of engines use is so huge that they are one of the primary causes of environment pollution. The intensive work on developing and extense use of so called alternate fuels from other than crude oil sources has been undertaken. Currently, the biofuels and biocomponents are of most interest. There is some diversity resulting mostly from requirements set by various appliances - engines. In case of spark engines the biocomponents with low boiling points, mostly alcohols and their derivatives - ethers are in use. In case of compression ingnition (CI) engines mostly fatty acid esters are employed. It is also possible to power CI engines with specially modified ethyl alcohol-based fuel. Also there is one more very large group of engines - the turbine ones. They use very large quantities of fuel, so they have much more emissions in relation to piston engines. Moreover, its more difficult to employ equipment for exhaust gases purifying or emissions restricting. It is important to replace oil-based fuel with alternate one that is less harmful to environment, even in the smallest extent. Of course there are also limitations, probably even more important than in case of fuels for piston engine. The primary limitation is engine purpose. The purpose determines engine operation conditions which in turn determine requirements regarding fuel characteristics. Though the rule of operation is similar, requirements regarding aviation engine fuels and fuels used in engines used at less severe conditions are quite different.

This paper covers fragment of the work regarding the possible use of fatty acid methyl esters (FAME) as component of hydrocarbon fuel. Selection of such biocomponent was conditioned by big similarity to base fuel (in the extent of essential physical and chemical properties) as well as availability. There is extended research work on various biocomponents in recent years however, FAME is the best recognized one so far. Besides, there are many manufacturers producing high quality products. This is very important since low quality would cause distortion of the results. Biocomponent was introduced into aviation kerosene (trade name Jet A-1). Intention of such selection was to check the application in as most severe as possible conditions. In such case every other application could be easier to fulfill requirements.

2. Description of selected physical and chemical properties

There are some stereotypes used as base to evaluate biocomponents usefulness. Main reason for their use is lubricity. This parameter is the best known and the most frequently mentioned as biocomponents advantage. Actually, presence of even small FAME amount results in significant decrease of wear of mating elements. But, it should be noted that lubricity is not everything. The second parameter “improving” fuel properties is flash point. After introducing biocomponent of lower volatility into kerosene, the flash point of such biofuel increases resulting in better safety of fuel use. Unfortunately, besides these two advantages we can yet add only one - less harmful effect on environment. Rest of properties doesn’t change with biocomponent content or become worse. It is not tantamount to elimination components of vegetable origin. It’s important to not to allow to worsen parameters that influence on later use. Parameters that can change after biocomponent introduction are the following:

+ lubricity improvement,
+ flash point increase,
+ lower emission of most of toxic and undesirable exhaust components,
− density change,
− kinematic viscosity increase, and greater vulnerability to temperature lowering,
− freezing point increase,
− possible acid number increase (particularly in case of poor FAME quality or ageing process starting),
− thermal stability worsening,
− boiling range increase (influence on distillation),
− existent gum content increase,
− sudden decrease of water separation index and water reaction index,

− possible corrosivity increase,
− net heat of combustion decrease,
− possible water conten increase,
− better conditions for microbial contamination.

Above mentioned are only some - the most important - changes caused by biocomponent presence in hydrocarbon fuel. As mentioned earlier, not all the changes can disqualify biofuel from use. Moreover, not all the mentioned changes can appear together at the same moment. This relates such properties that depend practically on manufacturing process parameters as water content, acid number, corrosivity, sulphur content etc. When components quality is appropriate, the quality and properties of finished biofuel (in above mentionet extent) don't change.

The characteristics of selected parameters regarding potential influence on fuel use in turbine engine are presented below.

3. Thermal stability

Thermal stability is recognized as fundamental reason for biofuels use restriction, especially in turbine engines. Performed tests confirm such thesis not entirely. Modern biocomponents are more often manufactured using technologies that allow to obtain stable product resistant to elevated temperatures. Antioxidants inserting is additional advantage.

Thermal stability testing in dynamic conditions (JFTOT) was performet according to modified technique consisting in repeated testing without change of fuel, test tube, and filter, until total disqualification of fuel. The results are presented on Fig. 1. From plots of upstream and downstream pressure it can be read that though cycle multiple repetitions there was no pressure increase showing building up of deposits - thermal decomposition products.

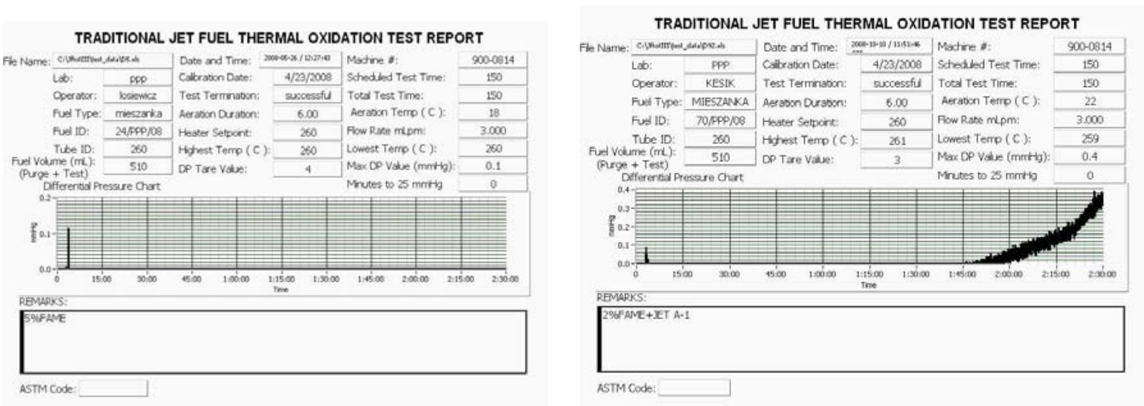
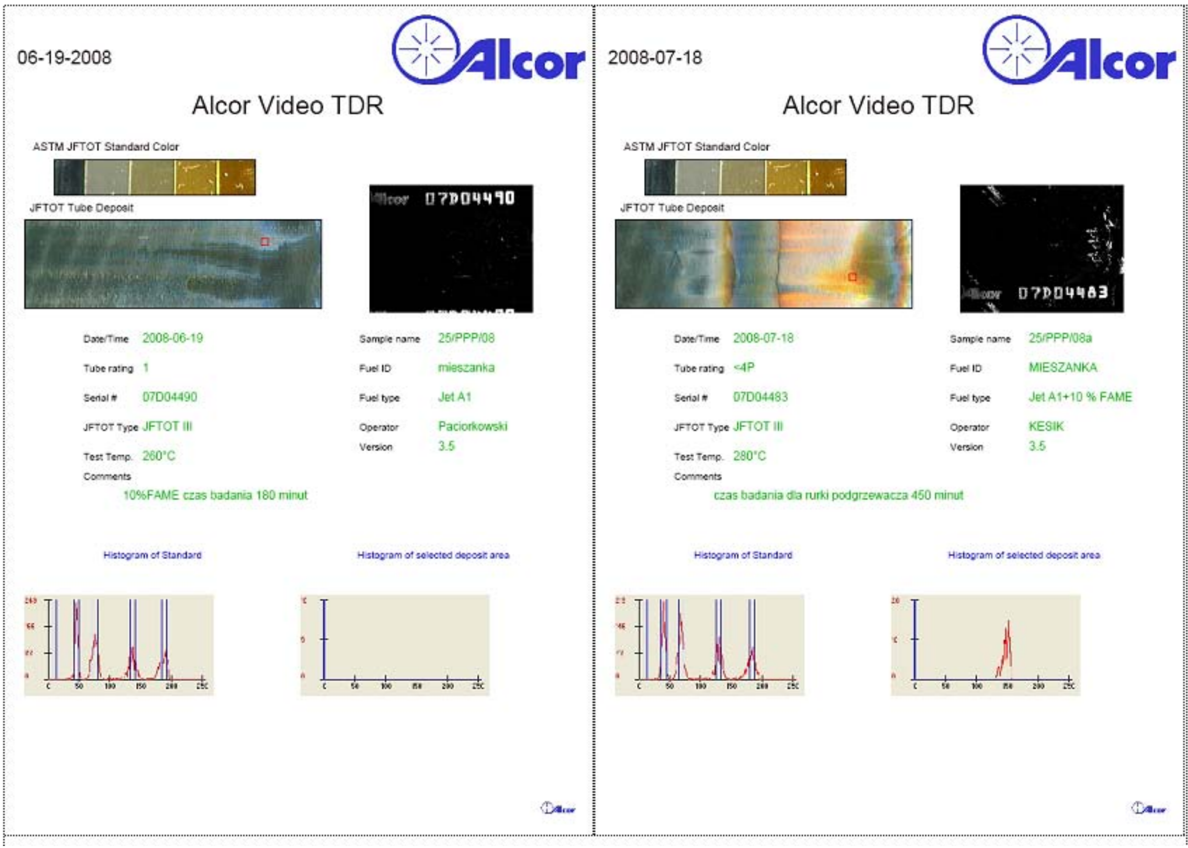


Figure 1. Example reports of thermal stability testing cycle course (cycle I and VI)

Spectra of tube deposits are displayed on fig. 2. It can be seen that coloured deposits were created after every 150-min cycles. Presence of such deposits formally disqualifies the fuel as usable. Test results of fuel with 10 % (*V/V*) biocomponent content showed that it behaves not worse than neat aviation fuel, so it's impossible to explicitly assess fuel applicability basing on this parameter.



Rys. 2. Example spectrum of tube deposit rating after thermal stability testing cycle course (cycle I and VI)

4. Rheological and low temperature properties

Flaw of biofuels is restricted use connected with effect of low temperatures having much stronger influence on biofuels rheological properties than on hydrocarbon ones. The most evident symptom is internal friction resistance. It has decisive influence on resistance to fuel flow in fuel lines, and on quality of fuel spraying. Preparation of fuel-air mixture has an effect on ignition and combustion process.

Too low viscosity causes at particular injection pressure that fuel atomisation is not complete. Such conditions create small droplets that slow down quickly in thickened air, so the combustion process takes place in the vicinity of injectors. This causes local fuel excess resulting in incomplete combustion.

Too high viscosity also disrupts air-fuel mixture preparation process. It’s because of too large fuel droplets that evaporate to slow causing incomplete combustion as well. Unburned fuel can build up on injectors causing injection characteristics change, and on other components of combustion chamber causing change of thermal properties of structural components. Moreover, range of the droplets is prolate causing combustion zone shifting. It can lead to shift flame front to inlet guide zone. This can cause excessive thermal effect on such components of engine. Moreover, too large droplets (coarse mixture) can have bigger range, so they can fall on vanes of inlet guide and on I-stage turbine causing mechanical degradation of their surface. Such phenomenon can, in the long range, lead to impairing external coating strength, and fatigue-based mechanical damages.

Too high viscosity also means pressure increase inside fuel system. This causes excessive forces generation in fuel system, especially in appliances generating high pressures leading to damages and leaking.

Introduction of FAME into traditional aviation turbine fuel means kinematic viscosity raise. So it is possible to meet problems caused by appearance of bigger particles and elevated pressures in supply system. According this we can assume that this parameter can restrict use of biocomponents.

There is another problem regarding kinematic viscosity. Viscosity depends on temperature and pressure, so environment conditions change influence on rheological parameters. Since the changes nature and course depend on substance construction, it is possible that course of viscosity changes can change according to particular mixture components. In case of aviation engine fuels such changes are very important (fig. 3).

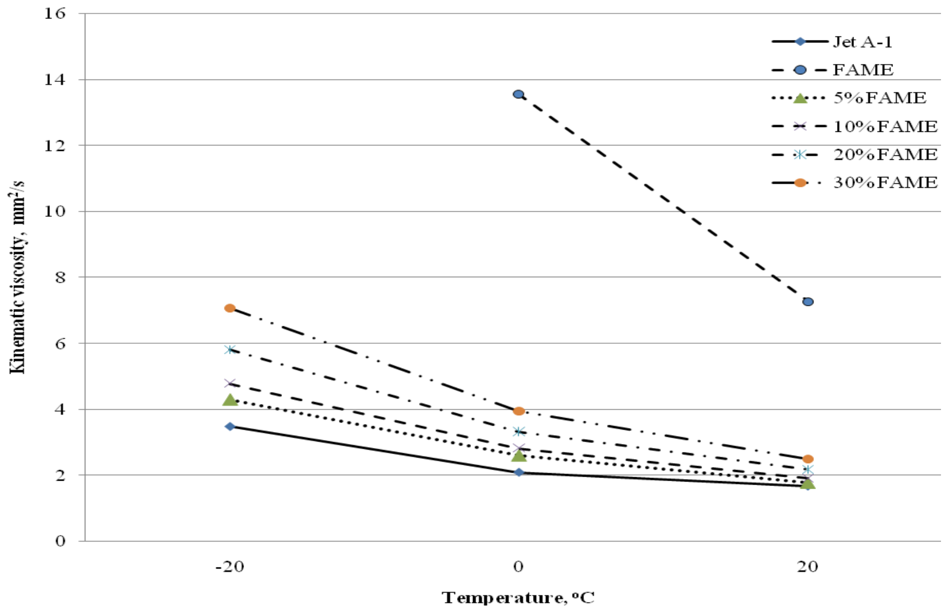


Figure 3. Viscosity change vs. temperature of aviation fuel, FAME and their mixtures

Decreasing ambient temperature causes product temperature lowering. At the beginning it causes mostly viscosity and density change, but beyond limit characteristics, the phase transition starts for every substance. The crystallisation starts. Since crystallisation temperature of individual components is different, there is no exact freezing point of the mixture.

Crystals start to appear in liquid phase. Their amount, or rather volume rise with temperature decrease. The fuel becomes cloudy though is still fluid that means it can be used safely. Further temperature decrease, however, leads to fluidity loss. Such situation is unacceptable, because it leads to fuel feeding continuity disturbance at the beginning (mostly due to filter sticking by crystals), and total breaking of fuel flow through the supply system.

In case of use of biocomponent that is vulnerable to low temperatures, there is serious threat and restriction regarding its use. First phase transitions of aviation fuels take place only under temperature of -50 °C, while in case of FAME first signs of crystallisation process beginning are visible at temperature under 0 °C a bit. So the discrepancy is huge. This can significantly restrict use of biocomponent in fuel.

5. Water separation tendency during filtration process

Hindered filtration at low temperatures due to filtration materials sticking can be intensified by water presence. In case of traditional turbine fuels, water presence is restricted using coalescence-separation filters during fuelling. Basic property used during use of these appliances is surface tension. Since the surface tension of fuel and water is different, the fuel passes through the filter gauze covered with surface-active material (i.e. polytetraflouoroethylene - PTFE), and small water droplets are trapped on filter gauze, and then they combine together, and flow to sediment trap as bigger drops. The FAME disturbs coalescence process, so the water removal is not sufficient. Such phenomenon is not connected with surface tension since its values for petroleum fuel and FAME are similar (accordingly 25.36 and 28.27). In comparison to surface tension for water (72.75) it shouldn't be a problem. The reason is different. At this stage of testing it can be supposed that FAME particles stick to coalescer surface and block its operation. Such hypothesis needs to be confirmed.

As a consequence of dewatering lack during fuel cooling down, water separation from fuel will take place at first (due to water solubility in fuel reducing with temperature decrease), and then the water can crystallize and can disturb engine fuelling process.

Tab. 1. Effect of biocomponent on properties connected with ability to fuel dewatering at coalescers

Pos.	Property	Biocomponent (FAME) content in aviation fuel % (*V/V*)				
		2	5	10	15	20
1	Water reaction: interface rating	2	3	>3	>3	-
2	Water reaction: interface separation rating	3	4	4	>4	-
3	Water reaction: water phase volume change, cm^3	1	1	1	-	-
4	Water separation index	39	0	0	0	0

6. Tendency to microbial contamination

In some cases, especially at positive temperatures, presence of small water content doesn't constitute problem for combustion process. In case of non aviation engines, water contained in fuel has, among others, even positive effect on harmful exhaust gases emission. However, it cannot be recognised that fuel dewatering is unnecessary. Every fuel is exposed to microbial contamination in presence of separated water. Due to perfect biodegradability, and hygroscopicity, biocomponents are very prone to microbial growth. Because it's impossible to maintain anhydrous fuel, the only way to prevent such infection is biocides use. However, it should be noted that biocides are mostly chemicals of relatively high aggressiveness, so they can have harmful effect on distribution and storage facilities, and on construction materials of involved engine components as well.

7. Summary

Basing on above test results and preliminary conclusions it can be found that there are some restrictions regarding use of biocomponents as ingredients of aviation turbine fuels. Obviously, such restrictions are more extensive in case of use in aviation, and less extensive for marine and land transport applications. According to performed testing, problems appear not only where they are obviously expected. The issues not fully recognized theoretically yet, and yet less utility experience can be the reason for that. Moreover, it’s possible that because of chemical diversity of petroleum fuels and biocomponents, analytic methods developed for the first ones, in some cases are unsuitable for the latter ones. As a consequence some test results distortion is possible, and in turn, false interpretation.

Results obtained by laboratory test methods should be verified by engine bench testing. This is the subject of the next stage of the research work.