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JET FUELS DIVERSITY

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Abstract

Term "jet fuel" is well known and recognized worldwide - it applies to aviation product used to power all turbine engines in aircrafts and helicopters. Its' properties are clearly and strictly defined in international specifications. However, in the discussion concerning jet fuels, and in most research material, many people seem to forget that this fuel is a mixture of different hydrocarbons, is produced from different feedstock (crude oil from different sources available worldwide) and as a final product is obtained with different production processes. Thus, however jet fuel must meet the requirements defined in international standards, these fuels differ each other and as a result, differences can be observed in logistic chain and in combustion process.

This paper points out some differences between jet fuels and its aim is to convict users, researchers and all people in aviation industry dealing with jet engines operation, that - when talking about jet fuel - many factors and details about final product must be considered, and this type of product should not be seen as single-type fuel, as most people see it now.

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***Keywords**: jet fuel, composition, hydrocarbons, jet engine, fossil fuels, surrogate fuels*

1. Introduction

There are two types of aviation fuels, used in jet engines:

- wide-cut, with carbon number distribution between C5 and C15,
- kerosene-type (i.e. JET A-1), with carbon number distribution between C8 and C16.

Kerosene-type jet fuel is the basic fuel used worldwide to power jet engines in civil and military applications. To be used, commercially available fuel delivered to aircraft must meet the requirements defined in international and national specifications, both civil and military, i.e. AFQRJOS [1], ASTM D 1655 [2], DEF-STAN 91-91 [3] or NO-91-A258-4 [4]. These documents are just examples as many standards defining requirements for jet fuel exist.

Fuels' quality is essential for proper operation of jet engine. Although jet fuels' requirements are strict, all of them define limits (minimum and/or maximum). As jet fuel is not a single hydrocarbon, its' composition can vary depending on production plant, production process and crude oil source. Fuels' specifications define of course limits for some components (aromatics, sulphur, synthetic components), but detailed composition (specific hydrocarbons content or group composition) is not defined.

Jet fuel is produced in 2 major processes: hydrotreatment and merox (mercaptan oxidation). Both are well known and described in literature, so they will not be compared and discussed here. The aim of this article is to present, how different two jet fuels produced in two different processes are and how differences in composition can influence their chemical properties and jet engines operation.

2. Experimental

To present, how different fuels covered by common name "jet fuel" or "JET A-1" can be, over 300 jet fuel samples produced by 2 different oil refineries using different production processes (merox and hydrotreatment) have been analysed. To establish baseline for comparison, results of fuels from each production process have been averaged, and compared with requirements according to standards currently used in civil aviation (ASTM D1655 and AFQRJOS). Additionally samples of fuels produced in merox and hydrotreatment processes were prepared and tested for their detailed composition.

2.1. Chemical properties comparison

Table 1 - below - presents selected parameters (averaged values) of jet fuels after testing over 300 samples produced by two oil refineries using different processes – merox and hydrotreatment.

Tab. 1. Selected averaged parameters of fuels from merox and hydrotreatment production processes

Item	Parameter	Unit	Merox	Hydrotreated
Volatility				
1	IBP	°C	152.8	150.2
	10% recovery	°C	164.0	174.8
	50% recovery	°C	176.2	202.4
	90% recovery	°C	195.0	234.6
	FBP	°C	211.0	249.6
2	Density @ 15°C	kg/m^3	786.7	800.9
Fluidity				
3	Freezing point	°C	-62.0	-52.5
4	Viscosity @ -20°C	mm^2/s	2.745	4.194
Combustion				
5	Specific energy	MJ/kg	43.306	43.282
6	Naphtalenes	% (V/V)	0.25	1.03
7	Hydrogen content	% (m/m)	13.91	13.85
8	Smoke point	mm	25.5	24.5
Composition				
9	sulphur, total	% (m/m)	0.142	0.028
10	sulphur, mercaptan	% (m/m)	0.0021	0.0001

Properties of both fuels are of course within limits defined in specifications, but some differences are clearly visible. These differences result from production process parameters and its nature (mercaptan oxidation vs. hydrotreatment), and fuels' composition (discussed and presented in the section below). Distillation curve (Fig. 2) is the best parameter to show both fuels difference.

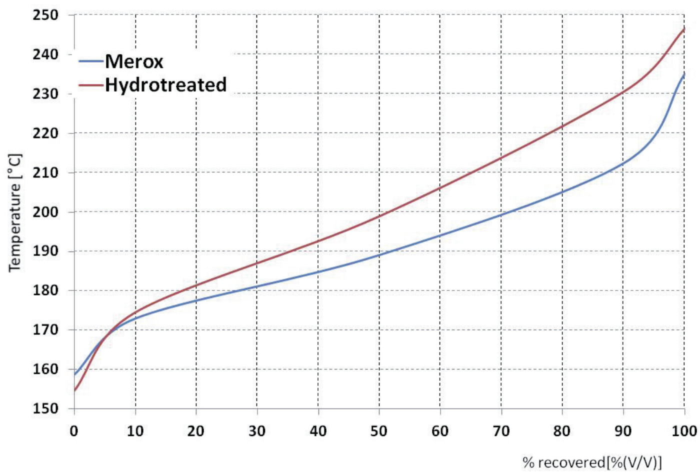

Fig. 1. Averaged distillation curves of merox and hydrotreated fuels

2.2. Composition of jet fuels produced in different processes

For each oil refinery/production, process average representative sample has been prepared. For each sample, detailed composition has been determined with gas chromatography with flame ionization detector (GC-FID). Aromatic components distribution has been determined with high performance liquid chromatography (HPLC).

Tab. 2. Composition of representative samples of merox and hydrotreadted fuels

Item	Property	Unit	merox	hydrotreated
Composition				
1.	saturates	% (m/m)	73.2	72.5
	n-paraffins		23.7	24.2
	iso-paraffins		29.5	32.3
	naphtenes		20.0	16.0
2	olefins	% (m/m)	2.6	0.4
3	aromatics	% (m/m)	24.2	27.1
	mono-aromatics (MA)		22.1	23.6
	di-aromatics (DA)		2.0	3.5
	tri- and poliaromatics (PA)		0.1	0.0

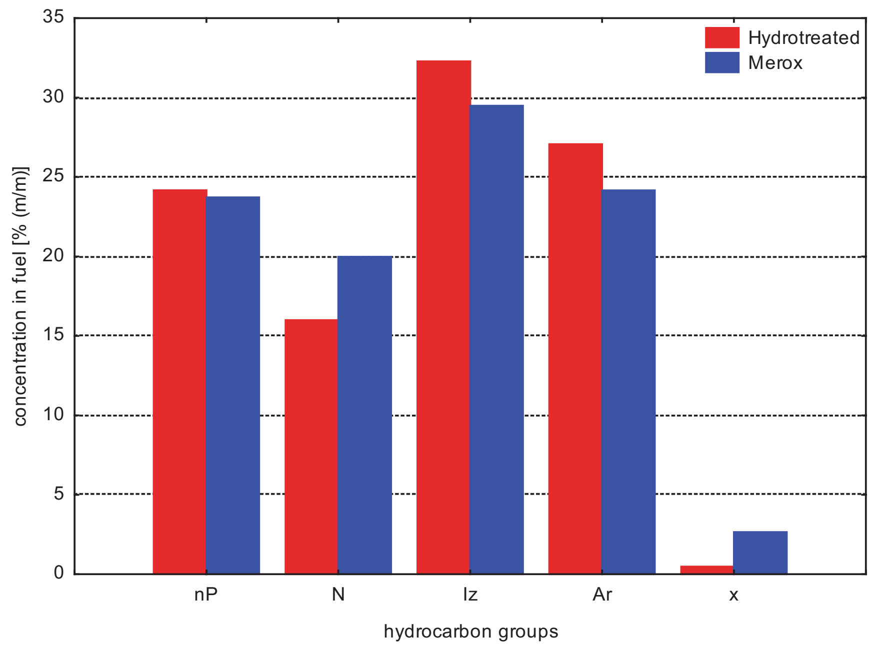

Fig. 2. Hydrocarbon groups present in merox and hydrotreated fuels being tested nP – normal paraffins, N – naphtenes, Iz – iso-paraffins, Ar – aromatics, X- unidentified

Hydrocarbon groups distribution (saturates, olefins, aromatics) for both fuels presented above in Tab. 2 and on Fig. 2 is similar, and it might suggest fuels similarity. However detailed analysis of both fuels revealed, that carbon number distribution in hydrocarbons molecules in each group is different (see Fig. 3-7) and it plays significant role in fuels characterization. Details are presented below.

On the basis of obtained results, it is clearly visible, that observed differences in two types of fuels (their composition) affect their properties and influence combustion and behavior in aircraft fuel system.

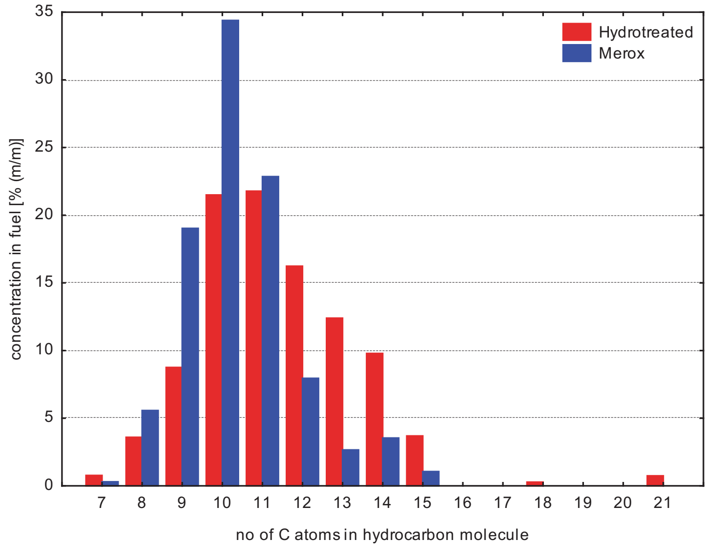

Fig. 3. Distribution of C number in hydrocarbons in merox and hydrotreated fuels being tested

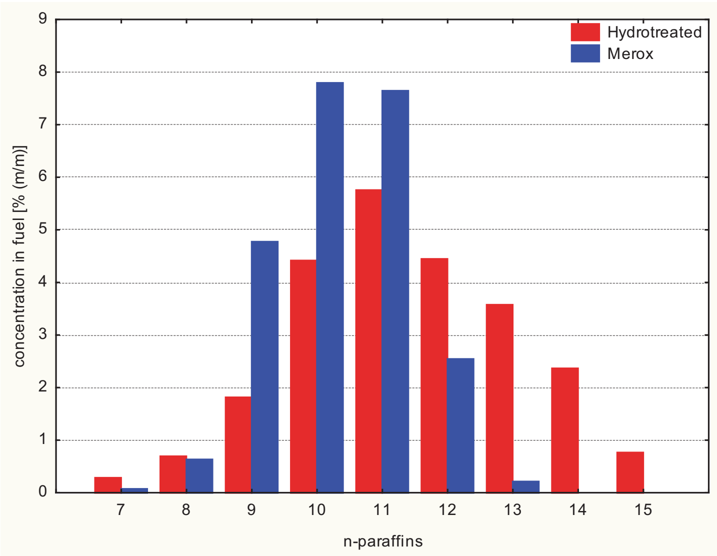

Fig. 4. Distribution of C number in n-paraffins in merox and hydrotreated fuels being tested

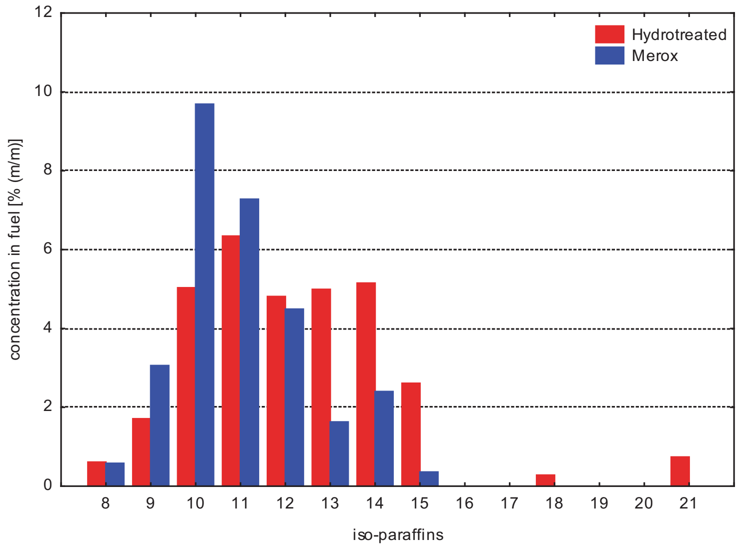

Fig. 5. Distribution of C number in iso-paraffins in merox and hydrotreated fuels being tested

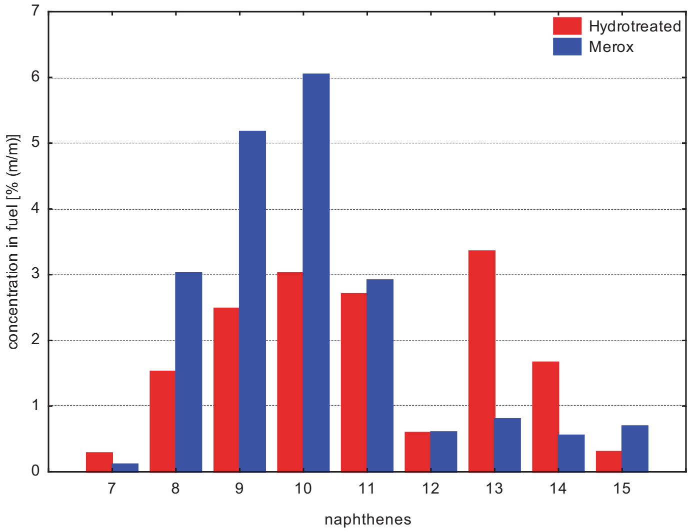

Fig. 6. Distribution of C number in naphtenes in merox and hydrotreated fuels being tested

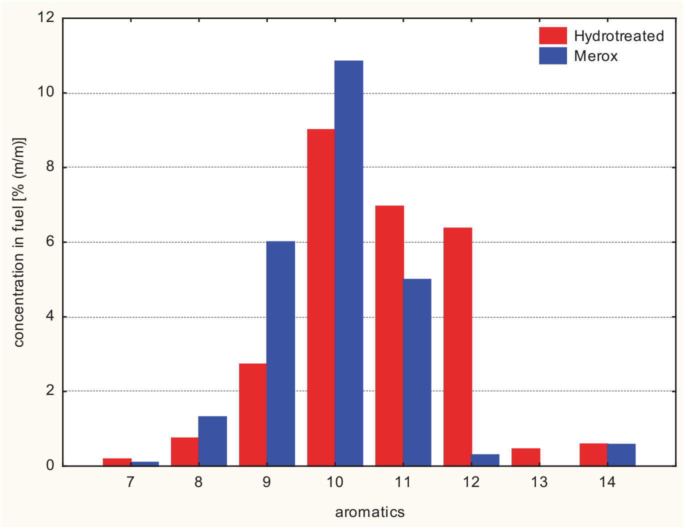

Fig. 7. Distribution of C number in aromates in merox and hydrotreated fuels being tested

3. Research results discussion

Research presented in previous section clearly shows, that jet fuels – being mixtures of different hydrocarbons – are different and thus when talking about this product, its' composition should be carefully analysed and considered in discussion.

Referring to composition differences between both fuels tested here:

- merox fuel: 75% (m/m) are C9-C11 hydrocarbons, and 90% are C9-C12, n-paraffins are mostly C9-C11, iso-paraffins C10-C12, aromatics C9-C11, naphetenes C8-C9,
- hydrotreated fuel: 70% (m/m) are C10-C13 hydrocarbons, and 90% are C9-C14, n-paraffins are mostly C10-C13, iso-paraffins C10-C14, aromatics C10-C12, naphtenes C9-C11 and C13. Some C18 and C21 hydrocarbons are also present in the fuel.

It can be stated, that both fuels will affect combustion process and will degrade thermally in different ways, which is determined by different properties of individual compounds.

Considering physical properties together with fuels composition – as hydrocarbons in hydrotreated fuel have more C atoms in molecules than merox fuel, it can affect:

- higher density of hydrotreated fuel than merox fuel,
- higher distillation curve of hydrotreated fuel than merox fuel (especially for 50% and higher percentage of fuel recovered).

Lower content of naphtenes in hydrotreated fuel results with higher freezing point and viscosity, when compared to merox fuel.

Higher sulphur content in merox fuel can result in higher deposits formation, as sulphur is known as natural antioxidant oxidizing quickly and initiating free radical mechanisms, and is a heteroatom that promotes deposit formation.

As antioxidant in hydrotreated fuel is mandatory, peroxidation in this fuel will probably occur only after additive's depletion. The role of this inhibitor is to break the reaction chain of the peroxy radical occurring during auto oxitation process.

Another problem to be considered on the basis of results presented here are surrogate fuels. Surrogates are mixtures prepared from pure hydrocarbons and are used for research purposes to simulate fossil fuels (to observe changes in combustion process and/or chemical properties) – usually they consist of 3 to 6 components.

The main idea of surrogates is to emulate alternative fuels, i.e. highly-parrafinnic Fisher-Tropsh jet fuel (>90% paraffins), or highly-naphtenic jet fuel from coal (>90% naphetenes). However, a lot of research worldwide is based on surrogates to emulate traditional jet fuel behavior (i.e. to monitor combustion characteristics or trends in chemical properties changing under different constraints). This approach however should be used carefully as jet fuel contains a lot of hydrocarbons from each group, and with different properties. Jet fuels – as presented here – are different and their composition depends on many factors, so results observed for surrogates can be not representative for fossil fuel. Even surrogates verified correctly to monitor changes of chemical properties under specific constraint (i.e. high temperature oxidation, specific engine test stand) can be not suitable for another constraint (i.e. low-temperature oxidation, storage stability or different test engine).

4. Conclusions

To conclude results presented in this paper:

1. Jet fuels meeting the requirements of international specifications have different hydrocarbon composition.
2. Differences in composition can result from crude oil sources, different production processes, or even from different parameters of production process in refineries worldwide.
3. Even fuels from the same refinery, where one production process exists, can have different composition resulting from crude oil sources or small modifications of production process' parameters.
4. General analysis of hydrocarbon groups present is not sufficient information to compare fuels, as within the same groups major differences may exist as a result of different C number.
5. Differences in composition of jet fuels affect their chemical properties, behavior in logistic chain (i.e. auto oxidation) and in aircraft fuel system (i.e. thermal degradation).
6. As a lot of research actually is based on surrogate jet fuels composed in laboratories from limited number of "representative" hydrocarbons for each group, the results should be carefully verified as:
   a. their suitability to represent behavior of real jet fuels can be questionable,
   b. they can simulate only few parameters of fossil jet fuels,
   c. even observed trends can be different for surrogate and fossil fuels.

References

[1] AFQRJOS *The Aviation Fuel Quality Requirements for Jointly Operated Systems*.

[2] ASTM D 1655 *Standard Specification for Aviation Turbine Fuels*.

[3] DEF-STAN 91-91 *Turbine Fuel, Aviation Kerosine Type, Jet A-1,* NATO Code: F-35.

[4] NO-91-A258-4 *Paliwo do turbinowych silników lotniczych*. Kod NATO F-35.