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Traditional and Alternative Jet Fuels: Problems of Quality Standardization

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Abstract

The main tendencies in sphere of civil aviation are discussed in the article, mainly ecologization of aviation, implementation of alternative fuels, increase and control of aviation fuels' quality. The keystone principles of policy in sphere of modern aviation development are presented. Peculiarities of the main international and Ukrainian normative documents determining requirements to jet fuels quality are discussed in the article. Special attention is paid to the necessity in harmonization of requirements set in Ukrainian and international normative documents.

Keywords: Fuels for air jet engines; Normative base; Environmental requirements; Quality; Aircraft engine Physico-chemical properties; Reliability

Introduction

Production of fuels for aircraft engines is one of the prior branches of the world oil-processing industry. First of all it is explained by the increase of Aircraft Park. According to the forecast of marketing firm Forecast International, by 2013 5,835 large passenger and cargo aircrafts will be built in the world. According to the data of analytical site www.indexmundi.com about 5.5 thousand barrels of fuel for Air Jet Engines (AJE) are produced and consumed all over the world daily.

Modern state in production and use of fuels for AJE

Requirements to quality of fuels for AJE are initially much higher than for gasoline and diesel fuels [1]. Quality of fuels for AJE comparing to other petroleum products depends mostly on the oil origin and boiling temperatures of oil fractions obtained during atmospheric distillation. Straight run distillates are purified in different ways, depending on the composition of crude oil and requirements for fuel quality. Some amount of fuel for jet engines is obtained by catalytic destructive processing of straight run or vacuum distillates and catalytic cracking products in a presence of hydrogen. Catalytic processing mode depends on the quality of raw materials and, in its' turn, almost completely determines fuel quality [2].

In recent years, some amount of fuels for AJE is produced from alternative raw materials such as coal, natural gas, oil sands, oil shale, and biomass [3]. Technologies used for processing of these types of feedstock allow obtaining of high-quality fuel, with the possibility to vary certain parameters if required. However, these technologies are quite energy-intensive and difficult for realization. So, refining of base kerosene oil fractions requires hydrotreating and various destructive methods; at the same time, obtaining of basic fractions from non oil-derived feedstock, in addition to mentioned stages, needs pyrolysis, FT-synthesis, gasification etc. [4]. Nevertheless, the limitation of the world's oil deposits still promotes development of alternative technologies for jet fuels production [5]. «BP» company has done a statistical review and forecast about the future development of the world energy industry. According to this investigation, the growth of crude oil consumption will gradually decrease, at the same time; the share of biofuels will continuously increase [6].

Environmental requirements to fuels for AJE

Modern environmental requirements also set additional requirements to quality of AJE fuels. For example, the European Parliament resolution on reduction of impact of aviation on climate change (INI/2005/2249) [7] clearly states that: "The European Parliament promotes introduction of aviation biofuels, thereby reducing the effects on climate change". International Air Transport Association (IATA) has set up the task to reduce the level of CO_2 emissions from air transport by 50% by 2050 (IATA, 2011) [8]. In addition, European Commision in 2011 has set a policy target of achieving a 60% reduction of CO_2 by 2050. Low-carbon fuels in aviation should reach 40% by 2050 [9].

At present days the basic principles of European policy in sphere of implementation and use of alternative fuels in aviation are identified in the following documents:

- Directive 2009/28/EC of the European Parliament and the Council on 23.04. 2009 "On stimulating the use of energy from renewable sources [10]."
- The agreement of the European Commission on 08/02/2006 "EU Biofuel Strategy" that determines seven strategic directions for development and production of biofuels by the member countries and developing countries [11].
- Directive 2009/30/EC of the European Parliament and the Council on 23.04. 2009, "On the technical requirements to gasoline, diesel and gas fuels, and introduction of a mechanism for monitoring and reduction of greenhouse gases emissions" (Directive on fuel quality) [12].

Modern normative base for quality of fuels for AJE

The possibility of using of aviation fuels for jet engines (AJE) with satisfactory performance all over the world is a basic requirement of international aviation. In September, 1957, in Stockholm, a meeting of representatives of airlines and fuel suppliers, and at the next meeting

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on the 10th Technical Conference IATA released IATA Guidance Document on aviation fuel for the AJE, used in civil aviation. The basic requirement of international aviation is the possibility to use fuels for AJE with satisfactory properties all over the world. During the meeting at the 10th IATA Technical Conference they have released IATA Guidance Document on aviation fuels for the AJE, used in civil aviation. On 4th March 2000 the IATA issued the Guidance Material on specifications for fuel for AJE. Today, the basic requirements to fuels for AJE form: IATA, the American Society for Testing Materials (ASTM), British specification (DERD) and "Check List". The most common fuel for AJE in the world is known as Aviation Turbine Fuel - Kerosene type (AVTUR) – Jet A-1 [13]. The quality of the fuel Jet A-1 is determined by the following standards:

- British standard Def Stan 91-91 Turbine fuel, Kerosene type, Jet A-1;
- American standard ASTM D1655 Standard Specification for Aviation Turbine Fuels;
- American standard ASTM D 7566 Standard Specification for Aviation Fuel Containing Synthesized Hydrocarbons.

British standard Defense Standard 91-91 specifies requirements for one fuel grade for AJE of kerosene-type, which is appropriate for use in gas turbine engines of aircrafts. Jet fuel, determined by this document should contain hydrocarbons obtained from traditional raw materials, including crude oil, heavy oil, oil sands and oil shales. Earlier this standard permits the use of fuels derived from crude oil only. However, since December 2011, it has included fuels that contain hydrocarbons synthesized from some non-oil sources. According to this standard synthetic paraffinic kerosene can be used as a component of traditional fuel for AJE in the amount up to 50% of volume. It should be also mentioned that Def Stan 91-91 does not define the process of synthetic fuel components production, but only the technical characteristics to be met by this kind of fuel for the AJE.

American Standard ASTM D1655 was firstly issued in 1959 and contained requirements to fuel for AJE of grades Jet A, Jet A-1 and Jet B. Similarly to standard Def Stan 91-91 it determines requirements to fuel for AJE of kerosene type designated for use in gas turbine engines of aircrafts. This document defines quality of fuels for AJE all life cycle stages: from production to fueling of aircrafts. Today, this standard provides only two grades of fuel for AJE: Jet A and Jet A-1-distillate fuels of kerosene type, with have relatively high flash point. Jet A and Jet A-1 are two brands of kerosene fuel, which have different freezing point. Similarly to Def Stan 91-91, these fuels must consist primarily of hydrocarbons obtained from traditional raw materials, including crude oil, heavy oil, oil sands and shale oil. Use of hydrocarbons synthesized from other new raw materials requires special guiding materials, which at this point are not considered in the standard ASTM D1655. This guide is included into the standard ASTM D7566. Standard ASTM D1655 describes also the use of various fuel additives (corrosion inhibitors, antioxidants, biocide additives, etc.)

American Standard ASTM D7566 was firstly enacted in 2009. It covers the production of fuels for AJE, which consist of a mixture of traditional and synthetic components. It determines certain types of fuels for AJE for civil aviation that contain synthetic hydrocarbons, and that are satisfactory for use in aircrafts. It is intended for determination quality of fuels for AJE and its synthetic components at all life cycle stages; from production to fueling of aircrafts. This standard provides two grades of fuel for the AJE: Jet A and Jet A-1-distillate fuels of kerosene type, with a relatively high flash point. According to the standard fuel for AJE should consist of traditional fuel grades Jet A or Jet A-1, which are in compliance with D1655, and up to 50% of the synthetic component, defined by this standard. For today standard ASTM D7566 determines only two technologies, according to which synthetic components are produced:

- Hydrogenated synthetic kerosene produced entirely from synthetic gas by the Fischer-Tropsch (FT) synthesis with further application of such traditional processes as hydrotreatment, hydrocracking, hydroisomerization, and also polymerization, isomerization and fractionation.
- Hydrogenated synthetic paraffinic kerosene derived entirely from esters of fatty acids and free fatty acids by their hydrogenation and deoxygenation, followed by processing with the above mentioned processes.

As we can see, the enlargement of raw materials for jet fuels production was reflected in the normative base by amending the standards Def Stan 91-91 and ASTM D1655, as well as introduction of a new standard ASTM D7566, which regulates jet fuels production from alternative raw materials.

The state of jet fuels production in Ukraine

In Ukraine two grades of fuel for AJE are produced: "PT" and "TC-1". The main producers of fuel for AJE are Odessa, Kremenchuk and Lisichanskiy oil processing plants. Requirements established to the quality of these fuels, are regulated by industry standards ГСТУ320.00149943.007 "Fuel for jet engines of "PT" grade. Specifications" and ГСТУ 320.00149943.011 "Fuel "TC-1" for jet engines. Specifications". Requirements to fuel of grade Jet A-1 that is imported into Ukraine are set by the State Standard ДСТУ 4796:2007 "Aviation Fuel for gas-turbine jet engines Jet A-1. Specifications".

With the entry of Ukraine into a common trade area the question about unification and optimization of requirements to products quality and aviation fuels in particular has raised.

The majority of countries, including such influential as China and India, produce jet fuels for civil aviation of Jet A-1 grade that correspond to requirements of standards ASTM D 1655 (USA) and DEF STAN 91-91 (Great Britain). Fuels for AJE produced in Ukraine–"TC-1" and "PT", have some differences with fuel Jet A-1. However, the major part of quality indexes of Ukrainian fuels are not worse than of Jet A-1, and some parameters are even superior. Analysis of the requirements to jet fuels quality set by Ukrainian, USA and British standards (Table 1) shows that some quality parameters of Ukrainian standards are more stringent than international ones.

The most widely used fuel in Ukraine of grade "TC-1" is produced mainly by straight-run distillation of crude oil, so that its physico-chemical and exploitation properties entirely dependent on the quality of processed oil. If this method does not allow obtaining of "TC-1" fuel of the required quality, then it is produced with application of hydrotreating or demercaptanization processes or by mixing of straight-run component with hydrotreated or demercaptanized one [14].

Fuel of grade "PT" comparing to "TC-1" is produced in much smaller amounts, with application of hydrotreating process. Quality of this fuel is higher than of "TC-1", especially in thermal stability.

Fuels of grade Jet A-1 can be produced by both straight-run distillation technology and with application of demercaptanization and hydrogenation processes.

Index	Meaning				
	PT	TC-1	Def Stan 91-91	JetA-1 (ASTM D 1655)	JetA-1 (ASTM D 7566)
Density, kg/m^3: at t_{20} °C at t_{15} °C	<775 —	<775 —	— 775—840	— 775—840	— 775—840
Distllation temperature: — start boiling point °C	unnorm.	unnorm.	—	—	—
— 10 % recovered, t °C	175	175	205	205	205
— 50 % recovered, t °C	225	225	report	report	report
— 90 % recovered, t °C	270	270	report	report	report
— 98 % recovered, t °C — final boiling point °C	280	280	— 300	— 300	— 300
Kinematic viscosity, mm^2/sec, — at t_{20} °C — at t_{-20} °C — at t_{-40} °C	< 1.25 < 16	< 1.5 < 16	— < 8 —	— < 8 —	— < 8 —
Net heat of combustion, MJ/kg	> 43 100	> 43 120	> 42 800	> 42 800	> 42 800
Smoke point, mm, or Smoke point, mm and naphtalenes, %	25 1.5 (mas)	25 3 (mas)	25 19 3 (vol.)	25 18 3 (vol.)	25 18 3 (vol.)
Acidity, total mg KOH/g	< 0.7	< 0.7	< 0.015	< 0.1	< 0.1
Iodine number, g of iodine per 100 g of fuel,	< 0.5	< 3.5		—	—
Flash point, °C	> 30	> 28	> 38	> 38	> 38
Freezing point, °C	< – 55	< – 55	< – 47	< – 47	< – 47
Thermal stability (static conditions): — amount of sediment, mg per 100 sm^3 of fuel, — critical temperature, °C, not less	<6 115	<18 115	— —	14 —	14 —
Thermal Stability, JFTOT (dynamic conditions): Test Temperature Tube Rating Visual Pressure Differential	— — —	— — —	> 260 < 3 <25	> 260 < 3 <25	> 260 < 3 <25
Aromatics, %	< 22 (mas.)	< 22 (mas.)	< 25 (vol.)	< 25 (vol.)	< 25 (vol.)
Existent gum, mg/100 mL	< 4	< 5	< 7	< 7	< 7
Sulfur, total mass %	< 0.1	< 0.25	< 0.3	< 0.3	< 0.3
Sulfur, mercaptan, mass %	< 0.001	< 0.003	< 0.003	< 0.003	< 0.003
Hydrogen sulfide content	Absence	Absence	—	—	—
Copper strip, 2 h at 100°C	Stand	Stand	No1	No1	No1
Ash content, %, not more	0,003	0,003	—	—	—
Interaction with water, separation surface, points	< 1	< 1		< 1	< 1
Specific electrical conductivity at t_{20} °C, pS / m	600	600	50 – 600	50 – 600	50 – 600
Content of mechanical impurities and water	Absence	Absence	Absence	Absence	Absence
Content of water soluble alkali compounds	Absence	Absence	—	—	—
Content of water soluble acids and alkalis	Absence	Absence	—	—	—
Content of naphthenic acid soaps	Absence	Absence	—	—	—
Lubricity: Wear Scar Diameter	0.95	0.95	0.85	0.85	0.85
High temperature corrosion: sample mass loss, g/m^2 under t_{20}, °C, — for copper — for bronze brand ВБ23НЦ	3.0 2.5	15 2.5	— —	— —	— —
Luminometric number, not less	50	50	—	—	—

Table 1: Comparative characteristics of quality requirements to jet fuel grades established by Ukrainian and international standards.

Ukrainian and foreign standards regulate almost the same exploitation characteristics of jet fuels, including anti-wear properties, determination of which is defined by DEF STAN 91-91 but did not provided by Russian standard ГОСТ 10227 [15]. Despite the fact that serial Ukrainian jet fuels of grades "TC-1" and "PT" considerably exceed jet fuel of grade Jet A-1 for a number of exploitation and physico-chemical properties, their use in an aircraft engines made by companies "Pratt and Whitney", "Rolls- Royce", "General electric" are significantly limited. European aviation authorities issued a European Directive AD 2012-0123 from 07.09.2012 on introduction of restrictions on the use of European Airlines jet fuel "TC-1". Internal fuel specifications, procedures of fuel quality control and Ukrainian governmental regulation contradicts with existing system of flight safety. To a greater degree it is connected with the different approaches to assessing the reliability of the aircraft, depending on the exploitation characteristics of fuels for AJE. One more reason for limitation of Ukrainian fuels use has a political base.

Technologies for production of "TC-1" and "PT" fuel grades were developed several decades ago. These technologies require certain technological schemes and equipment at the oil processing plants. For today these technologies are still well adjusted for production of high quality jet fuel. As it was mentioned, fuel of grade Jet A-1 is imported in Ukraine, and it is not produced. It may be explained by that fact that existing technological processes do not allow production of this fuel grade. At the same time building of new oil processing plant or organization of new production line requires too great investments. For today such expenses unfortunately are unallowable for Ukrainian economics.

Taking into account above mentioned, the aim of this article is to show that jet fuels produced in Ukraine are still of high quality and restriction for their use is seemed to be unjustified.

Peculiarities of Ukrainian and international standards for jet fuels

In Ukrainian practice reliable operation of fuel systems of aircrafts is estimated firstly by pumpability and fuels liability to form deposits. Pumpability is usually understood as fuel pumping ability at low and high temperatures. Fuel pumpability at low temperatures is determined mainly by the ability to pass through fuel filters and it is characterized by such indicators as freezing point, viscosity free and dissolved water [16]. Thus, according to the requirements of Ukrainian standards for jet fuels of grades "TC-1" and "PT" freezing point must be not higher than minus 55°C. At the same time, in standards ASTM D 1655, ASTM D7566 and DEF STAN 91-91 this index is rather overrated and should not be higher than minus 47°C. Ukrainian standards determine such index as viscosity at temperature of 20°C (not less than 1.25 mm/s^2) and at temperature of minus 40°C (not more than 16 mm/s^2). However, foreign standards define only upper limit of the viscosity at temperature of minus 20°C–8 mm/s^2. Thus, it is clear that requirements of Ukrainian normative documents to the mentioned indexes are more stringent comparing to foreign specifications. Fuel viscosity is one of the basic properties that provide proper lubricating characteristics of fuel. From the Table 1 it is seen that Ukrainian standards set more strict requirements to fuel lubricity comparing to ASTM D 1655, ASTM D7566 and DEF STAN 91-91. As for the content of mechanical impurities and water, affecting the fuel pumpability, all the standards require their absence. Pumpability of fuels at high temperatures is determined by thermal stability, size and shape of insoluble deposits formed during heating and characteristics of the filter. Thermal stability of fuels for AJE is determined by their oxidation resistance at certain exploitation temperature range [13]. This index is characterized by the mass of forming deposits and gums, and also by speed of filter clogging. Thermal stability of fuels at high temperatures decreases in the presence of gums and sulfur compounds, especially mercaptans. Unsaturated compounds in fuels can be easily oxidized, in this regard, their content is limited. Ukrainian standards characterize their content by such index as iodine value. But standards ASTM D 1655, ASTM D7566 and DEF STAN 91-91 do not determine this index at all. According to these documents thermal stability is determined in dynamic conditions, while the Ukrainian standards provide definition of this index, both in dynamic and in static conditions (in addition the required norms are much higher). Ukrainian standards also set more stringent requirements to the content of existent gums in fuels for AJE.

In foreign countries fire safety is considered to be the dominant exploitation property of fuels for AJE. In general, fuels for AJE are considered as fire dangerous and are related to flammable liquids. They are characterized by high volatility and heating capacity, easily form flammable mixtures with air. Jet fuels form a great amount of combustion materials when burning and can easily accumulate static electricity. The main exploitation index that determines flammability of fuels for AJE is flash point. Differences in requirements to fire safety of Ukrainian and foreign jet fuels are reflected in the Ukraine standards (ГСТУ), the Russian Federation standards (ГОСТ 10227), the American standards (ASTM D 1655 and ASTM D7566) and the British standard (DEF STAN 91-91). Thus, the minimum value of the flash point for fuel of grade "PT" is 30°C, for grade "TC-1"–28°C, while the flash point of fuel of grade Jet A-1, should be at least 38°C. Higher flash point of fuels for AJE is achieved by making their fractional composition heavier, mainly by increasing the content of aromatic hydrocarbons. This peculiarity of jet fuels is also reflected in normative documents. Ukrainian standards specify a maximum content of aromatics as 22% (by mass). However, content of aromatics in foreign standards should not exceed 25% (by volume), If calculated into percents by mass it is about 27%. So, it is seen that foreign standards determine higher limit for aromatics content. Increase of the aromatic hydrocarbons content, in its turn, affects the processes of fuel burning results in increased coke formation and smoking of aircraft exhaust gases [13]. As it is seen from the table 1In order to

Thus, some differences in Ukrainian and foreign requirements to quality of fuels for AJE, and, therefore, limitation of Ukrainian fuels use on foreign aircrafts is related with different approaches to assessment of jet fuels quality, their reliability and safety. All over the world, the main criterion for assessment of fuels safety during exploitation is fire safety. In Ukrainian practice, the quality of fuel is estimated by its ability to ensure reliable operation of aircraft engines. Detail analysis of the factors affecting these parameters has shown that they are mutually exclusive. The increase of fuel fire safety results in worsening of its burning characteristics.

Conclusions

Production of jet fuels is faced to such problem as limitation of the main raw material – crude oil. This results in development of new alternative technologies of aviation fuels production from non-oil resources. This found reflection in international normative base for jet fuels quality by making amendments in existing standards and introduction of new ones.

Ukrainian oil processing plants are equipped with modern equipment that allows producing high quality aviation fuel. Quality of Ukrainian fuels is not worse than quality of the best foreign samples and for some parameters is even superior. However, differences in norms for individual quality indexes and methods of their testing, do not allow suggesting Ukrainian fuels correspondent to foreign fuel. Thus, it is reasonable to harmonize and unify normative documents that establish technical requirements to fuels for AJE.

The established experience for limitation of Ukrainian fuels use in aircrafts engines of foreign producers is seemed to be unreasonable. Basing on the analysis done it is necessary to restrict the use of foreign fuels for Ukrainian aircrafts because of the poor anti-wear properties.

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