ЭКОЛОГИЯ ЖӘНЕ ӨМІРТІРШІЛІК ҚАУІПСІЗДІГІ
ECOLOGY AND LIFE SAFETY
ЭКОЛОГИЯ И БЕЗОПАСНОСТЬ ЖИЗНЕДЕЯТЕЛЬНОСТИ

UDK 547.9 DOI 10.52167/1609-1817-2022-124-1-442-451

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COMPARATIVE ANALYSIS OF THE PHYSICO-CHEMICAL PROPERTIES OF BIOFUEL AND AVIAKEROSINE

Abstract. Current trends in the development of civil aviation indicate the need to improve the efficiency and environmental friendliness of the fuels used. The use of traditional jet fuel to a lesser extent meets the promising requirements for environmental friendliness at a constantly growing price for it. In addition, oil reserves are not unlimited. According to many experts, the solution to the growing problems with petroleum fuels can be the use of alternative types of aviation fuel. A number of companies in different countries of the world, together with aircraft manufacturers, with significant state support, are actively developing new types of fuel. The most common at the moment biofuels, consisting of bioethanol, obtained from various plant and animal sources. Alternative types of fuels should not be inferior to petroleum fuels in terms of their operational properties. A possible transition to them should not require significant costs for the modernization of aircraft and means of ground aviation fuel supply. Therefore, an urgent task is to compare the main indicators of the quality of petroleum fuels of biofuels and their mixtures to assess the possibility of using biofuels on aircraft.

Keywords. Biofuel, kerosene, alternative fuels, hydrocarbons, comparative analysis.

Introduction.

The use of fuel on an aircraft is produced by distillation from oil. Currently, oil reserves are depleted, and the price of its extraction and processing is growing (Figure 1) [1]. Under these conditions, the issue of research and application of biofuels on modern aircraft becomes relevant.

The development of alternative fuels is actively pursued by such countries as the USA, China, EU countries, Canada, etc. Now synthetic kerosene is already produced on an industrial scale from coal and natural gas and is approved for use on aircraft according to the ASTM D 7566-09 specification (Standard for fuel for aircraft gas turbine engines containing synthesized hydrocarbons)

There are also pilot plants for the production of biofuels from algae. It should be recognized that in the issue of creating biofuels, Kazakhstan is inferior to these countries.

The use of alternative fuels is also relevant in the Republic of Kazakhstan. However, this is largely due to the use of gas fuels [2]. The use of alternative fuels for aircraft can make air travel more environmentally friendly and more affordable. The world community is seriously raising the issue of reducing emissions from the use of aviation, despite the fact that this is only 2 ... 3% [3].

Thus, there is a need for a comparative assessment of the characteristics of biofuels with traditional kerosenes. For practical application, it is preferable to carry out experimental work to determine the parameters of fuels, including flight tests. However, this is difficult both in terms of labor costs and from an economic point of view. Therefore, for the initial assessment, an analysis of the physicochemical properties of various biofuels, their mixtures with traditional grades of kerosene and kerosenes themselves was carried out in order to make a decision on their use on an aircraft. The fuel used affects the reliability of engines, their specific consumption and thrust.

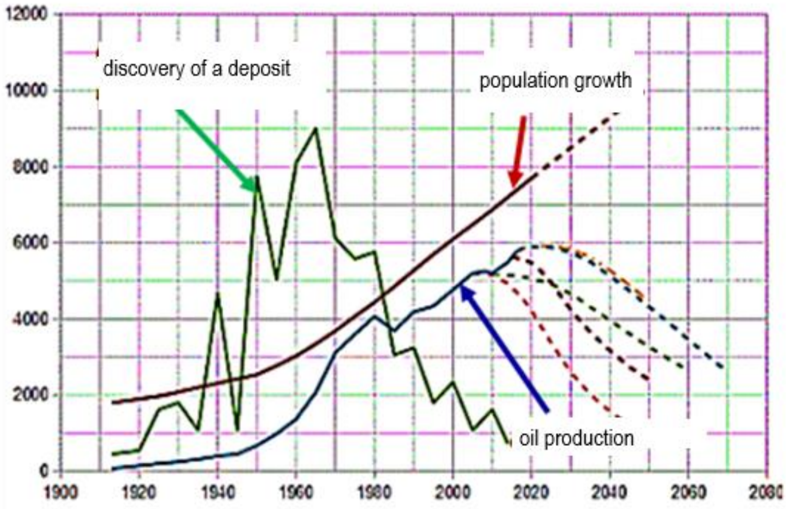

Figure 1 - Forecast of oil production

Methods and methods.

Evaluation of used aviation fuels and their mixtures with biofuels for justification and correlation of characteristics and emissions based on the development of mathematical models.

Results and Discussion.

Comparative analysis of aviation fuels.

Depending on the type of aircraft, the mass of the refueling aircraft can be 40-65% of the total mass of the aircraft that passes through pipelines, pumps, fuel control equipment, which means that its quality will affect their performance and flight safety. This dictates the need to impose stringent requirements on the quality of the fuel used [4]. The most promising direction for the use of alternative fuels is the creation of combined mixtures. That is, fuel is produced from the plant, which has good, but insufficient characteristics for direct use in an aircraft. To improve the physico-chemical properties, special additives made from petroleum raw materials are introduced into it. The introduced additives can worsen the environmental parameters of such a mixture, but will increase other indicators, due to which such a mixture can be more efficient than the kerosene used.

The most important thing in this case is to maintain a balance between the development price, the amount of harmful emissions, the resulting thrust and the specific fuel consumption. The right combination of these indicators can provide reductions in harmful emissions. In order to select jet fuel or a mixture of biofuel and kerosene for use on an aircraft in operation, we will conduct a comparative assessment of the physicochemical properties of traditional kerosenes and alternative fuels and technologies for their production. One of the most promising is synthetic jet fuel, manufactured according to ASTM D 7566-09 specification [5], which is approved for use in aircraft. It is a blend of synthetic paraffinic kerosene (SPK) with traditional Jet A-1 kerosenes. Such kerosene (SPK) is produced by the Fischer-Tropsch (FT) technology from coal or natural gas according to the reaction:

$$CO + nH_2 \rightarrow (-CH_2-)x + H_2O.$$

Antioxidant additives are introduced into the fuel to reduce the oxidation of SPC. The fuel obtained by this technology has a low content of aromatic compounds and sulfur. Due to the low aromatics content, there may be technical problems associated with the shrinkage of the seal to prevent fuel leakage. The minimum content of aromatic compounds should not be less than 8% [6]. As a result of the hydrogenation of fatty acids and esters (HEFA), another type of biofuel is obtained, where plant types of biomass (seaweed, camelina, jatropha and camelina) are raw materials for obtaining such fuel. And as a result of the hydrotreating of oils, another type of biofuel, HVO, is obtained. Fuel can be obtained from a wide range of vegetable oils. The essence of this technology is that oils (triglycerides) interact with hydrogen under a sufficiently high pressure in order to remove oxygen from them.

The hydrocarbon chains resulting from this technology are chemically similar to petroleum-derived diesel fuel. With this technology, a by-product is formed - propane, which can also be used as fuel. The terms HVO (Hydrotreated Vegetable Oil) and HEFA (Hydroprocessed Esters and Fatty Acide) are used to denote the sources of raw materials for such fuels - vegetable oils and fats.

The production of biofuels using HVO technology, the main sources of raw materials are primarily tall oil, as a by-product of paper and pulp production, soybean, rapeseed or corn oils. This technology allows the use of animal fats as raw materials. According to researchers [7], the raw materials for the production of biofuels using HVO technology are distributed as follows: slaughterhouse waste is 35%, vegetable waste, including other animal waste, 23%, tall oil, 22%, and palm oil, 15% and animals. fats - 5%. Therefore, a comparative study of the physicochemical characteristics and performance properties of FT SPK biofuel, mixtures of HEFA SPK and HDO SAK biofuels with kerosenes and various proportions, and TC-1, Jet A-1 petroleum kerosenes was carried out in the work. Such a comparison will determine the most appropriate proportions of these for research in civil aviation. Let's compare some properties of well-known brands of kerosene and three variants of biofuel mixed with Jet A-1 kerosene in various proportions (Table 1). Using the data of Table 1 and the data of sources [8], we will carry out the corresponding calculations.

Table 1 - Comparative characteristics of kerosenes, biofuels and their mixtures with kerosenes

Characteristic fuel	**TS-1**	**RT**	**Jet A-1**	**100% FT SPK in Jet A-1**	**50% FT SPK in Jet A-1**	**50% HEFA SPK in Jet A-1**	**17% HDO SAK in HEFA SPK**
Density at 15 C	786.0	775.0	814.8	759.9	786.6	784.9	775.3
Fractional composition of 10% distillate	150.0	135.0	173.8	158.6	160.7	155.8	148.4
of 98% distillate	250.0	155.0	259.8	220.9	250.0	268.5	276.2
net calorific value, MJ/kg	43.2	43.1	43.1	43.8	43.6	43.0	43.6
volumetric calorific value, MJ/m^3x10^3	33.9	33.8	35.1	33.2	34.3	33.8	33.8
volume fraction of aromatic hydrocarbons	17.0	20.0	18.3	0.5	17.5	10.4	15.0
kinematic viscosity at -20^0C, cSt	4.3	4.2	4.7	3.5	3.9	4.5	3.8
mass fraction of sulfur, %	0.17	0.1	0.19	0.0	0.14	0.144	<0.0003
smokeless flame height, mm	26.0	25.0	22.0	40.0	28.0	32.0	28.6
hydrogen content, %	14.0	14.1	13.7	15.3	15.0	14.5	14.4
carbon content, %	86.0	85.8	86.1	84.6	85.0	85.3	85.5
hydrogen to carbon ratio	0.16	0.16	0.6	0.18	0.18	0.17	0.17

The density of the used aviation fuel is one of the important indicators of the fuel and is determined by its chemical composition and the quality of production during oil refining. The take-off weight of the aircraft, and consequently, its power-to-weight ratio, depends on it. For example, a decrease in fuel density by 40 units leads to a decrease in flight range by about 5%. The density of fuel depends on temperature - when heated, due to thermal expansion, the density of kerosene decreases. Analysis of the studied fuels and biomixtures (Table 1) shows that they are close in values and have satisfactory density values.

The fractional composition of aviation fuel is its most important characteristic. Analysis shows that adding 50% FT SPK to Jet A-1 improves this performance. 100% FT SPK has good results. The most important property of a fuel is its lower calorific value. It determines the calorific value of the fuel used, on which the fuel efficiency of the aircraft depends. The high calorific value of the fuel used leads to an increase in fuel efficiency. As can be seen, the analyzed petroleum kerosenes, biofuels and their mixtures have approximately the same values for this indicator.

To further assess the influence of properties on characteristics, it is advisable to compare such an indicator of fuels as its volumetric calorific value, which is defined as the product of mass calorific value and fuel density. Table 1 shows that the multipliers (densities) of the studied kerosenes, biofuels and their mixtures have slight differences, which leads to slight differences in the indicator under consideration.

Biofuels have a lower viscosity compared to kerosenes, which is preferable from the point of view of the listed characteristics. Another important characteristic of the fuels used is the non-smoking flame height, that is, the maximum non-smoky flame height (MHNP), which characterizes such an indicator of fuel as carbon formation. The way to determine it is to measure the height of the flame, defined in millimeters, achieved before the appearance of smoke, when fuel is burned in a standard lamp under certain conditions. The maximum non-smoking flame height (MSFL) depends on the composition of hydrocarbon fractions in the fuel:

$$h=0.48P + 0.32C + 0.20A,$$

where h is the smoke point, mm;

P, C, A - respectively, the content of paraffinic, cyclane and aromatic hydrocarbons, wt.%.

As can be seen, aromatic hydrocarbons show the greatest influence on the maximum smokeless flame height (MFLH). Those. the correlation between the value of non-smoking flame and the volumetric content of aromatic hydrocarbons in the studied fuels is visible. Therefore, it can be said that the lower the value of the height of the non-smoky flame of the fuels used, the less it burns, which means that carbon formation during the combustion process is higher and environmental friendliness is lower. For pure biofuels, the maximum non-smoky flame height (MFNR) is much higher than that of kerosenes.

Sulfur and its compounds in fuels are undesirable compounds. Fuels with a high sulfur content are corrosive, which leads to a decrease in the service life of structural products of the fuel systems of an aircraft and an aircraft engine. The best in this indicator is clean biofuel, since it does not contain sulfur in its composition, and when mixed with Jet A-1, it also reduces the sulfur content in it.

Fuel efficiency can be estimated by comparing their calorific value. In turn, the calorific value of a fuel is characterized by the ratio of its hydrogen to carbon content. Carbon has a much lower heat of combustion per mass unit than hydrogen. This makes it possible to compare the studied fuels in terms of such an indicator as the mass calorific value of its combustion.

As can be seen from Table 1, the values of the ratio of hydrocarbons for biofuels and mixtures with kerosene are somewhat better than for pure kerosenes. However, the ratio of hydrocarbons also characterizes the carbon-forming properties of fuels. Those. the lower this ratio, the higher the carbonization of the fuel. In addition, an increase in the ratio of hydrocarbons leads to a decrease in the density of the fuel, which, as can be seen from Table 1, for pure biofuels is lower than the density of petroleum kerosenes and their mixtures with biofuels. Thermal stability is an important indicator of a fuel. Its evaluation is carried out in static and dynamic conditions. Under dynamic conditions - on the JFTOT instrument.

Thus, the comparison of the main properties of traditional kerosenes, biofuels, as well as their mixtures, carried out in the work, showed that the main indicators of the studied fuels have values \u200b\u200bthat are permissible according to the requirements of regulatory documents and can be applied on an aircraft. During operation, under the influence of various factors, these indicators may change. Therefore, the determination of the physicochemical properties of both the biofuel itself and its mixture with traditional kerosene under various conditions of their operation, as well as their influence under these conditions on the operation of the fuel-control equipment of the engine, pumps, etc., their interchangeability, requires additional operational research. In general, biofuels, and especially their mixtures with petroleum kerosenes, meet the requirements for aviation fuels and can be applied to an aircraft.

Theoretical substantiation and calculation of the choice of fuel mixture with ratios of biofuel and kerosene.

Aviation fuel quality indicators have a significant impact on engine performance, such as throttle response, specific consumption, thrust, etc.

As noted above, today's technologies for the production of biofuels from various types of raw materials make it possible to obtain it with the performance of aviation kerosene, but so far it has not been possible to completely replace it. A comparative analysis of the properties of aviation kerosenes and biofuels obtained by various methods, carried out in the work, showed that it is most expedient to use mixtures of biofuels and kerosene on board an aircraft. It remains to clarify the question - what proportion of kerosene and biofuel should be in such a fuel mixture.

The resulting mixture must meet the requirements for it according to current regulations in order to ensure that engine performance is obtained. Biofuels and kerosene have their own quality indicators.

It can be noted that a change in the calorific value of such a mixture ultimately affects the thrust and specific fuel consumption [9]. It can be seen that a comparative assessment of the obtained indicators of a mixture of biofuel and kerosene is of not only theoretical, but also practical interest. To develop a calculation model for evaluating the properties of a mixture of biofuel and kerosene, the calculation formulas of the authors [10] were used in the work. To carry out the calculations, we used the indicators of kerosenes and synthetic biofuel SPK, presented in Table 2. This calculation allows us to evaluate the main indicators of the mixture in order to select the percentage ratio in the mixture of biofuels and traditional kerosenes.

Table 2 - Main indicators of the properties of SPK petroleum kerosenes

Characteristic fuel	**TS-1**	**Jet A-1**	**100% SPK**
Density at 15 C	0.786	0.8148	0.7599
Fractional composition of 10% distillate	150.0	173.8	158.6
of 98% distillate	250.0	259.8	220.9
net calorific value, MJ/kg	43.2	43.1	43.8
volumetric calorific value, MJ/m^3x10^3	33.9	35.1	33.2
volume fraction of aromatic hydrocarbons	17.0	18.3	0.5

kinematic viscosity at -20^{0}C, cSt	4.3	4.7	3.5
mass fraction of sulfur, %	0.17	0.19	0.0
smokeless flame height, mm	26.0	22.0	40.0
hydrogen content, %	86.0	86.1	84.6
carbon content, %	14.0	13.7	15.3
hydrogen to carbon ratio	0.16	0.16	0.18

Let us first consider the change in the basic properties of jet fuels. First of all, these include the density of the fuel (p) and the mass heat of combustion (Hu). Figures 1 and 2 show these dependences of the Jet A-1 with SPK and TC-1 with SPK fuel mixtures on its composition. It can be seen that the addition of biokerosene to petroleum kerosenes reduces their density in direct proportion to the increase in the percentage of biokerosene, which is quite understandable. Table 2 shows that biokerosene has a higher mass calorific value and its addition to kerosene increases it in direct proportion.

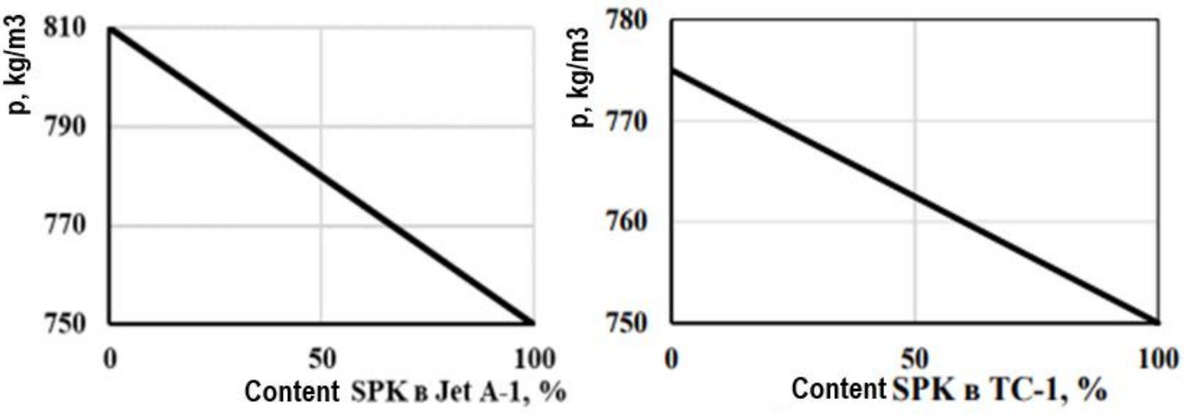

Figure 1 - Dependence of the density of the fuel mixture on its composition

Let's analyze such a change in the density of the air-fuel mixture from the percentage of biokerosene in it. As you can see, the density changes in direct proportion when added to both Jet A-1 and TS-1. Such a decrease in density leads to a decrease in the power-to-weight ratio of the aircraft and, consequently, to a decrease in the flight range. It is known that the density of the fuel changes with temperature, so the use of 100% biokerosene as the main fuel can lead to a reduction in flight range by 10%.

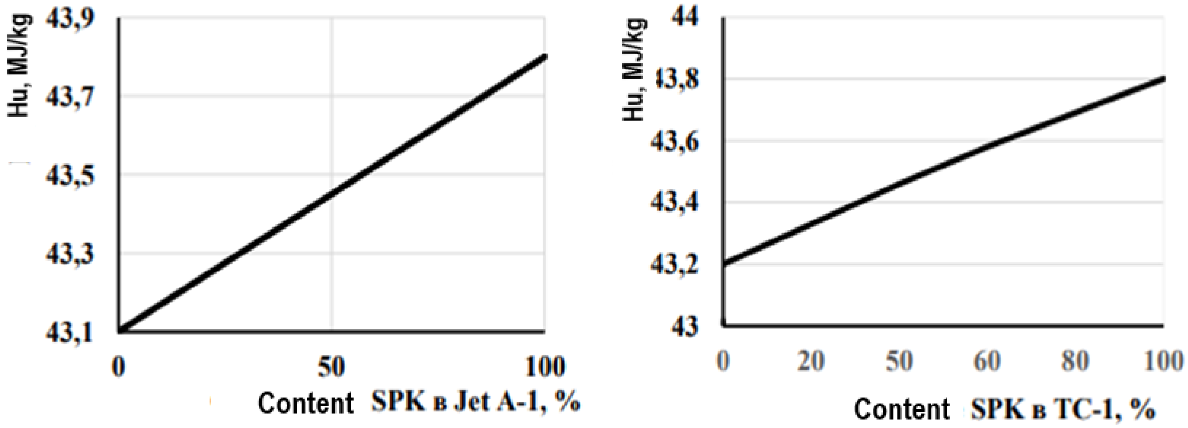

Figure 2 - Dependences of the mass calorific value of the fuel mixture on its composition

An important characteristic of fuel is the volumetric heat of combustion (Hy), which allows comparison of an aircraft in terms of such a characteristic as its power-to-weight ratio. The volumetric heat of combustion is defined as the product of fuel density and its mass heat of combustion. Since the value of the product is directly proportional to the percentage of the fuel mixture, the volumetric heat of combustion also has a linear dependence (Figure 3)

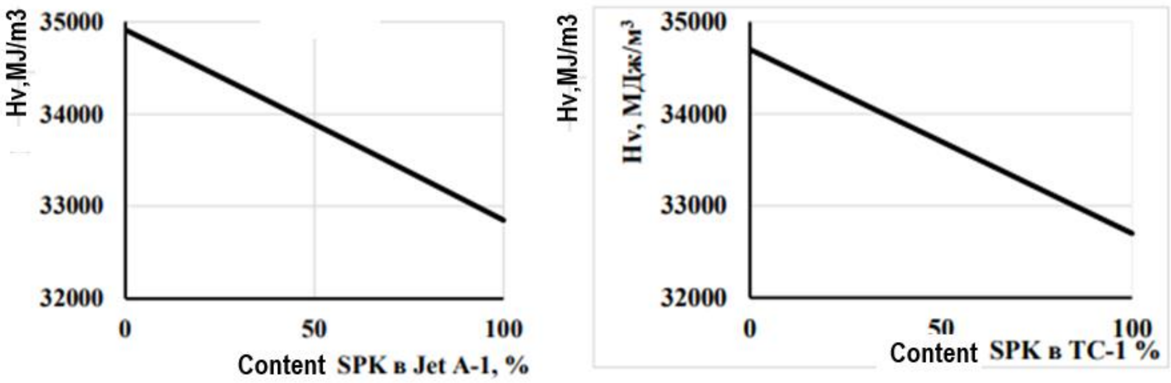

Figure 3 - Dependence of the volumetric heat of combustion of the fuel mixture on its composition

To carry out the combustion process, oxygen contained in the air is used as an oxidizing agent. Therefore, with the known chemical composition of the fuel used and the required mass of the oxidizer for the complete oxidation (combustion) of the air-fuel mixture used (Table 3), the following mass of air (stoichiometric coefficient ($L0$)) will be required:

$$L_0 = 4.33 * G_0 = 4.33 * (2.66g_C + 7.94g_H + g_S). \quad (1)$$

Table 3 - Mass of oxidizer required for complete oxidation of fuel elements (stoichiometric ratio)

Reaction	Oxygen consumption, kg	Air consumption, kg
$C + O \rightarrow CO_2$	≈2.66	≈11.52
$H_2 + 0,5 * O_2 \rightarrow H_2O$	≈7.94	≈34.38
$S + O_2 \rightarrow SO_2$	≈1.00	≈4.33

The stoichiometric coefficient, as is known, depends on the carbon-hydrogen ratio in the air-fuel mixture used. For further calculations of the influence of the composition of the fuel used on the characteristics, we simplify this formula, namely, we neglect the mass fraction of sulfur (gS) in the fuel. After simple transformations, the formula for calculating the stoichiometric ratio of the air-fuel mixture will be as follows:

$$L_0 = \frac{\frac{8}{3}g_C + 8g_H}{\psi O_2}. \quad (2)$$

In the process of organizing the combustion process in the combustion chamber, the real composition of the air-fuel mixture is somewhat different from the stoichiometric one. The difference between the actual composition of the air-fuel mixture and its stoichiometric composition is estimated by the excess air coefficient - this is the excess of the oxidizer in relation to its mass in the stoichiometric mixture. It can be calculated using the formula:

$$\alpha = \frac{G_0}{L_0 * G_T}. \quad (3)$$

Depending on the value of the coefficient α, when organizing the combustion process, a rich mixture is distinguished, when the value of the coefficient α is in the range from 0.85 to 1.25, and a lean mixture, when the value of the coefficient α is over 1.25.

The calculation of indicators of biofuel and its mixture with kerosenes carried out in the work showed that a significant increase in the content of biofuel in a mixture with traditional kerosenes reduces the ratio of hydrocarbons in such a mixture, which, in order to organize the combustion process, requires an increase in the required gas flow through the engine, which means an increase in its size and mass, which is not desirable, and with an increase in the content of biofuel in traditional kerosene (over 7%), it leads to an increase in the temperature of the combustion products of the mixture, and, consequently, to an increase in the required excess air coefficient, as well as to a decrease in kinematic viscosity, which positively affects the fineness of its spray in the combustion chamber and the pumpability of the fuel mixture through the fuel equipment. But with a decrease in the viscosity of the mixture below the critical value (approximately less than 1.3 cSt), lubricity decreases.

Based on the calculations of the quality indicators of biofuel and its mixtures with kerosenes and a comparative analysis of these indicators, it was found that it is most expedient to use a 1:1 mixture of SPK and Jet A-1 as jet fuel for an aircraft, which allows for acceptable operational technical characteristics does not require changes in the infrastructure of the existing aviation fuel supply system and changes in the design of the functional systems of the aircraft and aircraft engines.

The evaluation and justification of the effectiveness of the studied fuels showed that when using biofuel or its mixture with kerosenes, the cost of refueling an aircraft increases, but the amount of harmful emissions and specific fuel consumption decrease. The results obtained make it possible to further improve the use of fuel mixtures of petroleum kerosenes and biofuels to reduce harmful emissions into the environment and obtain rational throttle altitude characteristics depending on operating conditions.

Conclusion.

Thus, the calculations carried out in the work and the analysis of the results obtained show that the addition of biokerosene to petroleum kerosenes leads to a change in their physicochemical properties. At the same time, a number of indicators improve, and a number, on the contrary, worsens. Each of the studied indicators has a different impact on overall performance, as indicated above in the study of each individual indicator. The weight of the contribution of each individual indicator is difficult to assess, since many indicators are interrelated and have both the same and opposite effects. The calculations carried out allow us to conclude that the most rational ratio of the mixture of SPK and Jet A-1 and TS-1 kerosenes is 50:50.

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БИООТЫН ЖӘНЕ АВИАКЕРОСИННІҢ ФИЗИКАЛЫҚ-ХИМИЯЛЫҚ ҚАСИЕТТЕРІН САЛЫСТЫРМАЛЫ ТАЛДАУ

Аңдатпа. Азаматтық авиацияны дамытудың қазіргі тенденциялары пайдаланылатын отынның тиімділігі мен экологиялық тазалығын арттыру қажеттігін көрсетеді. Дәстүрлі авиакеросинді пайдалану оның тұрақты өсіп келе жатқан бағасы бойынша қоршаған ортаға зиянсыз болу талаптарын аз дәрежеде қанағаттандырады. Сонымен қатар, мұнай қоры да шексіз емес. Көптеген сарапшылардың пікірінше, мұнай отынына қатысты өсіп келе жатқан мәселелерді шешу авиациялық отынның балама түрлерін пайдалану болуы мүмкін. Әлемнің әртүрлі елдерінің бірқатар компаниялары авиациялық өндірушілермен бірлесе отырып, елеулі мемлекеттік қолдау көрсету арқылы жанармайдың жаңа түрлерін белсенді түрде игеруде. Қазіргі уақытта әртүрлі өсімдік және жануарлар көздерінен алынатын биоэтанолдан тұратын биоотын ең көп таралған. Отынның баламалы түрлері пайдалану қасиеттері бойынша мұнай отындарынан кем түспеуі керек. Оларға ықтимал көшу әуе кемелерін және жердегі авиациялық отынмен қамтамасыз ету құралдарын жаңғыртуға айтарлықтай шығындарды талап етпеуі керек. Сондықтан биоотын мен олардың қоспаларының мұнай отынының сапасының негізгі көрсеткіштерін әуе кемелерінде биоотын қолдану мүмкіндігін бағалау үшін салыстыру кезек күттірмейтін міндет болып табылады.

Түйінді сөздер. Биоотын, керосин, балама отындар, көмірсутектер, салыстырмалы талдау.

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СРАВНИТЕЛЬНЫЙ АНАЛИЗ ФИЗИКО-ХИМИЧЕСКИХ СВОЙСТВ БИОТОПЛИВО И АВИАКЕРОСИНА

Аннотация. Современные тенденции развития гражданской авиации указывают на необходимость повышения эффективности и экологичности применяемых топлив. Применение традиционного авиакеросина все в меньшей степени удовлетворяет перспективными требованиям по экологичности при постоянно растущей на него цене. Кроме того, запасы нефти не безграничны. По мнению многих специалистов, решением нарастающих проблем с нефтяными топливами может быть использование альтернативных видов авиационного топлива. Ряд компаний в разных странах мира совместно с производителями авиационной техники при весомой государственной поддержке активно разрабатывают новые виды топлива. Наиболее распространены на данный момент биотоплива, состоящее из биоэтанола, полученные из различных растительных и животных источников. Альтернативные виды топлив по своим эксплуатационным свойствам не должны уступать нефтяным топливам. Возможный переход на них не должен требовать значительных затрат на модернизацию воздушных судов и средств наземного авиационного топливообеспечения. Поэтому актуальной задачей является проведение сравнения основных показателей качеств нефтяных топлив биотоплив и их смесей для оценки возможности применения биотоплив на воздушных судах.

Ключевые слова. Биотопливо, керосин, альтернативные топлива, углеводороды, сравнительный анализ.

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