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CHANGE IN THE MAIN INDICATORS OF OIL QUALITY IN THE PROCESSES OF AIRBUS H-145 HELICOPTERS OPERATION

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Abstract

The operating conditions of synthetic Mobil Jet Oil 254 and mineral MK-8P oil in the turboprop engines of Airbus H-145 helicopters were analyzed. The study showed that the temperature in the nodes of the mechanisms can reach 150–200 °C during operation, which leads to changes in the physico-chemical and operational indicators of the quality of lubricating materials. The dynamics of changes of the kinematic viscosity and the total base number was studied. The change in kinematic viscosity for 300 h of oils' working time in the helicopter at the standard measurement temperature of 100 °C is shown. It is about 5 % for synthetic Mobil Jet Oil 254 and more than 18 % for mineral oil MK-8P. The change of kinematic viscosity at the negative standard temperature of its measurement (–40 °C) is less dependent on temperature for synthetic oil than for mineral oil. This makes Mobil Jet Oil 254 more attractive for lubricating engine mechanisms from a tribological point of view. The study showed that the base number of mineral oil MK-8P decreases by almost 50 % with increasing service life up to 300 hours and falls more sharply than synthetic Mobil Jet Oil 254, which indicates the deterioration of additives in it. According to the performed research, it is not recommended to use MK-8P mineral oil in the lubrication system of Airbus Helicopters H-145, as the oil is not suitable for a long time to maintain the main quality indicators when operating in the reducer. Research on changes in the quality of oils in the process of their actual operation in the lubrication system of helicopters is relevant in terms of providing recommendations on the timing of their replacement.

Keywords: synthetic oil Mobil Jet Oil 254; mineral oil MK-8P; quality indicators; kinematic viscosity; total alkalinity number; additives; Airbus H-145 Helicopter.

ЗМІНА ОСНОВНИХ ПОКАЗНИКІВ ЯКОСТІ ОЛИВ У ПРОЦЕСІ ЕКСПЛУАТАЦІЇ ГЕЛІКОПТЕРІВ AIRBUS H-145

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Анотація

Проаналізовано умови роботи синтетичної (Mobil Jet Oil 254) та мінеральної (МК-8п) олив у турбогвинтових двигунах гелікоптерів Airbus H-145 та показано, що у процесі експлуатації температура у вузлах механізмів може сягати 150–200 °С, що призводить до зміни фізико-хімічних та експлуатаційних показників якості змащувальних матеріалів. Розглянуто динаміку зміни двох найважливіших показників якості авіаційних олив – кінематичної в'язкості та загального лужного числа. Показано, що зміна кінематичної в'язкості за час напрацювання олив у гелікоптері 300 год за нормативної температури вимірювання 100 °С для синтетичної Mobil Jet Oil 254 становить біля 5 %, а для мінеральної МК-8п – понад 18 %. За від'ємної нормативної температури вимірювання кінематичної в'язкості (–40 °С) її зміна для синтетичної оливи менше залежить від температури, ніж мінеральної, що з трибологічної точки зору робить Mobil Jet Oil 254 більш привабливою для змащування механізмів двигуна. Показано, що лужне число мінеральної оливи МК-8п зі зростанням напрацювання до 300 год зменшується практично на 50 % та падає стрімкіше, ніж синтетичної Mobil Jet Oil 254, що вказує на спрацювання у ній присадок. За результатами проведених досліджень не рекомендовано застосовувати мінеральну оливу МК-8п у змащувальній системі гелікоптерів Airbus H-145, оскільки олива не придатна тривалий час зберігати основні нормативні показники якості під час роботи в редукторі. Дослідження зміни якості олив у процесі реальної їх роботи в змащувальній системі гелікоптерів є актуальними щодо надання рекомендацій по термінам їх заміни.

Ключові слова: синтетична олива Mobil Jet Oil 254; мінеральна олива МК-8п; показники якості; кінематична в'язкість; загальне лужне число; присадки; гелікоптер Airbus H-145.

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Introduction

The important directions of ensuring the reliability of turboprop engines (TPE) are the control of the performance of lubricating oils and the determination of changes in quality indicators during operation. They affect the periodicity and term of oil replacement [1].

Modern TPEs have high rotation speeds of the turbine rotor, high gas temperatures, multi-stage increase in air pressure and temperature in the compressor. This results in significant thermal loads on friction units and oils. The latter perform the functions of not only lubricating materials to reduce friction and wear of parts, but also of cooling the friction unit [2].

Lubricating materials interact with the mechanisms of aircraft equipment when operation and accumulate information about the normal or abnormal operation of the equipment in the result of such interaction. This information includes thermodynamic, chemical and frictional processes occurring in lubrication units and systems.

Oils change their physical and chemical parameters in the working process in the rotor's bearings under the influence of external factors such as temperature, pressure, presence of air oxygen, active action of metals. This is a complicate complex process, which includes a change in the chemical and physical parameters of the oil during operation [3].

The analysis of physico-chemical parameters during the operation of aviation techniques helps to make early detection of possible breakdowns or malfunctions and avoid expensive repairs or further damage to parts [4].

The lack of oil quality control during operation and determination of the limit state of their indicators do not guarantee the reasonableness of the terms of their replacement in accordance with real working conditions. Therefore, it is relevant to conduct a study of in the dynamics of changes in the physico-chemical quality indicators of oils during the operation of aviation techniques. Observance of this norm will contribute to increasing the efficiency of the use of oils and reducing costs, which confirms the ecological and economic expediency of carrying out work in this direction [5].

Periodic control of the dynamics of oil quality indicators helps to accumulate statistical data on the resource of oil operation and the periodicity of its replacement in the lubrication system of rotor bearings and reducer of helicopters.

Oil aging during operation in engines is a very complex process. The increased temperature and presence of air oxygen which contacts with the oil cause oxidation and oxidative polymerization of its molecules. Hydrocarbon oxidation products such as resins and organic acids are present in the oil in a dissolved state and contribute to an increase in viscosity and acid number. Asphaltene compounds, which are the basis for the formation of varnishes, are deposited on the surfaces of parts and prevent the withdrawal of heat from them. Products of deep oxidative polymerization are deposited in high temperature zones. They can flow back into the crankcase and deteriorate the normative indicators of oil quality [6].

Thus, a complex mixture of oil with various products of its aging is formed in the crankcase of a working engine. It is impossible to completely clean the oil from aging products by filtration and this causes accumulation of a great number of polluting particles in it [7].

The most modern oils should ensure the performance of mechanisms in a wide range of temperatures (from minus 50–70 to +300–360 °C). A significant increase in oil viscosity when cooling and its decrease when heating can disrupt the normal functioning of machines and mechanisms [8].

Viscosity modifiers are used to prevent sudden changes in viscosity with temperature (viscosity index increase) and to improve oil pumpability at low temperatures [9].

Viscosity (thickening) modifiers are high-molecular polymers with variable solubility in oils at different temperatures. They allow to increase the viscosity of oils and reduce the change in viscosity in case of temperature change. Viscosity modifiers thicken base oils less at low temperatures than at high. Various polymer and copolymer products are used as viscosity additives: polyisobutene, polymethacrylates, polyvinyl alkyl ethers, olefins copolymers, styrene-diene copolymers [10; 11].

The higher the molecular weight of the polymer, the better its ability to thicken, but the greater the tendency to thermomechanical destruction.

The mechanism of action of viscosity additives is not fully defined. They can prevent sudden changes in oil viscosity over a wide range of temperatures due to the ability of polymer macromolecules to change their configuration depending on temperature, namely to roll into spheres under high temperatures and to stretch long linear structures under low ones.

The use of effective additives of various functional effects allows to obtain the required level of operational properties of modern engine oils. Compositions of additives or packages are put on the market in most cases. Additives are conventionally divided into the following types according to their operational effect:

- antioxidant additives improve the antioxidant resistance of the oil, reduce its consumption and increase the service life [12];
- anti-corrosive additives protect metal surfaces from the corrosive action of oxygen- and sulfur-containing products and moisture [13];
- detergent dispersants contribute to the reduction of oxidation products deposits on metal surfaces [14];
- additives that improve the lubricating properties of oils – anti-wear, anti-seize and anti-friction [15];
- viscous (thickening) modifiers improve the viscosity-temperature properties of oils;
- depressant additives reduce the solidification temperature of oils;
- antifoam additives prevent foaming of oils.

This package of additives includes compounds of a partially acidic and basic nature, but preference is given to the latter, that is, the pH of the oil should be 7, or slightly higher.

The incomplete neutralization of acids leads to a more acidic oil medium in the engine. Corrosion processes can develop in such medium and negatively affect engine details.

Antioxidant resistance is the most important performance characteristic of engine oil, which determines the duration of its operation. Hydrocarbons of petroleum products undergo oxidation, destruction, polymerization and many other chemical transformations under the influence of air oxygen, high temperature, load and metal catalysis.

Acidic products and resins are formed at the same time and affect the alkalinity of oil. Oxidation products are hard to dissolve in oil and contribute to the formation of deposits and soot, causing corrosion and increasing the wear of parts.

Antioxidant additives protect hydrocarbons from oxidation by interacting with formed free radicals (R•, ROO•) or converting hydroperoxides (ROOH) into a stable state, interrupting and preventing the development of chain reactions.

All these oil additives contribute to the reserve of alkalinity. The ability of detergent dispersants, antioxidant, anti-corrosion additives to neutralize acids depends on their quantity and strength. Measurement of oil alkalinity is the most common method of assessing the ability of additives to neutralize acids during its operation.

The formation of oxidation products is the main criteria for replacing any oil, in addition to the deterioration of the additive package. Heating of oils in the presence of oxygen even to their operating temperatures reduces the thermo-oxidative stability of hydrocarbons and leads to the formation of a solid phase in the form of sediment and resins. They deposit on the parts of the oil system, change its lubricating characteristics and cause filter contamination thus reducing the efficiency of heat exchange devices [16].

Rolling bearings are the main lubrication units in turbojet aircraft engines in contrast to the lubrication units of piston engines in which sliding friction prevails. The temperature of the outer cage of such bearings is created due to the heat coming from the turbine impeller and reaches 125–150 °C. The air blowing is reduced after the engine stops and the heat flow coming from the impeller heats the bearing cage and lubricating oil thus removing heat from the friction zone to a temperature of more than 200 °C.

The temperature in the friction nodes increases sharply in turbojet engines of supersonic aircraft both due to the increase in the load on the turbine bearings and due to the heat coming from the combustion chamber and the turbine impeller. At the same time, the temperature of the oil rises. The temperature in the friction nodes can reach 400 °C and even 540 °C, and the oil temperature up to 200 °C in promising supersonic turbojet engines. Liquid mineral oils are unsuitable for the work at such temperatures and synthetic oils must contain anti-wear and antioxidant additives that would perform their functions under such conditions.

Therefore, it is quite relevant to study of the dynamics of the quality indicators of aviation oils operating at high temperatures and significant loads.

The results of research on changes in the physico-chemical properties of car engine oils are mainly presented in the scientific literature, while information on aviation oils is practically absent due to the specifics of their use.

Premature replacement of oil is unprofitable from an economic point of view and also creates problems of its further use and ecological burden on the environment. Increasing the life of the oil is one of the possible ways to solve this problem .

The purpose of the work is to study the process of changing the physicochemical indicators of oils, namely, kinematic viscosity and total base number during the operation of the Airbus H-145 helicopters [17].

The following tasks were solved to achieve the purpose:

- determination of kinematic viscosity and total base number of mineral MK-8P and synthetic Mobil Jet Oil 254 oils during their operation in turbojet aircraft engines;
- to analyze and evaluate the efficiency of the use of mineral and synthetic oil in helicopters.

Materials and Methods

Synthetic Mobil Jet Oil 254 and mineral MK-8P engine oils were investigated.

The large transmitting power of aviation reducers combined with their small weight and dimensions leads to increased operating conditions of friction pairs, an increase in thermal and dynamic stress of engine parts and assemblies. Gears of reducers work under conditions of high contact loads. It turns out to be insufficient the strength of the films of low-viscosity aviation oil (MK-8P), which is suitable for lubricating the supports of turbojet engines under given conditions. Oils with a higher viscosity and higher lubricating capacity are required to ensure reliable lubrication of the gears of the reducer. At the moment, the synthetic oil Mobil Jet Oil 254 meets these requirements.

Mobil Jet Oil 254 is an extremely high performance synthetic oil for the third generation gas turbine engines. It is developed according to their requirements and used in commercial and military aviation. This product is made from a specially formulated base synthetic oil with complex ether and is enriched with an additives package. The oil has excellent thermal and oxidative stability with an effective operating range from minus 40 °C to plus 230–250 °C.

The viscosity of synthetic oils at temperatures of 250-300 °C is higher than that of mineral oils of equal viscosity at temperature of 100 °C. They have better thermal stability, low evaporation and low tendency to high-temperature deposits and foaming. Their service life is several times longer than the service life of mineral oils due to this [18].

Viscosity or internal friction is the property of a liquid to create resistance to the relative movement of layers, that is, it is the force of internal friction between layers of liquid.

Kinematic viscosity is the main physical and mechanical characteristic of petroleum and synthetic lubricating oils. It characterizes the oil's ability to carry out hydrodynamic mode of lubrication at operating temperature, that is, the ability to replace dry friction with liquid friction and thus prevent rapid wear of the material. Therefore, viscosity is a standardized indicator for lubricating oils. The viscosity of oils is standardized at different temperatures depending on technical conditions of oils production. The viscosity is normalized at temperatures of 50 °C (ν_{50}) and 100 °C (ν_{100}) for aviation mineral oils. The kinematic viscosity is normalized at temperatures of +40 and +100 °C and minus 40 °C according to ASTM D445 for modern imported synthetic aircraft oils, for example, Mobil Jet Oil 254.

Kinematic viscosity is determined according to DSTU GOST 33-2003, GB/T265-1988, ISO 3104-94, ASTM D445, DIN 51366 at these temperatures.

The method of determination consists in measuring the time in seconds of outflow of a defined volume of liquid under the influence of gravity through a calibrated glass capillary viscometer. The required time of flow for a certain volume of oil through the calibrated capillary of the viscometer is measured in the experiment:

$\nu = tC$,

where t is the liquid outflow time, s; C is the viscometer constant (taken from the viscometer passport). Kinematic viscosity has a dimension of mm^2/s, or centistokes (1 cSt = 10^{-6} m^2/s = mm^2/s) according to the international system of units.

Kinematic viscosity is determined by manual (Fig. 1) or automatic measurement according to ASTM D445.

The viscometer is filled with the tested oil. To do this, a rubber ball is attached to the side end, the viscometer is turned over and the narrow tube is immersed into the oil. The oil product is pulled up to the M1 mark with a rubber ball after the wide tube closed with a finger. After that, the viscometer is turned over to the working position, the narrow tube is wiped from the oil and installed in a thermostat heated to the required temperature. The viscometer is kept in the thermostat for at least 15 minutes at the test temperature.

Next, the oil is pumped into the extension of the viscometer slightly above the M1 mark with the help of a rubber ball attached to the end of the narrow tube. Remove a rubber ball and observe the flow of liquid through the capillary. It is detected the time of descent of the liquid meniscus from the mark M1 to M2.

Fig. 1. Device for determining oil viscosity

Automatic measurement of kinematic viscosity performes by the following procedure according to the ASTM D445. The sample is placed in the selected capillary viscometer, and subsequently the viscosity is measured and calculated automatically. The oil flow time through the capillary should be at least 200 s [19].

Mineral and synthetic base oils are neutral, they have a pH value of around 7 on a scale of 0 (extremely acidic) to 14 (extremely basic). However, the pH value is affected by modifiers that are added to the base oil. Some combinations like anti-wear and anti-corrosion additives have a slightly acidic reaction. The content of acidic compounds in oils also continues to increase during their operation in the engine, for example, as a result of the oxidation of hydrocarbons.

The prevention of deposits on engine parts and bearings is one of the most important functions of engine oil, in addition to lubrication. That is the ability to keep the engine clean and to neutralize acidic combustion products that can get into the oil. Detergent and dispersing additives provide these oil properties. Total base number (neutralization number, TBN, mg KOH/g) is the evaluation of detergent and dispersing additives [20].

Acid pollution can occur from various sources, including oxidative and thermal processes. This can lead to the accumulation of byproducts that increase the wear of parts and reduce their tribological characteristics [21].

The total base number is determined by the potentiometric titration method [22] according to the national standard of Ukraine DSTU 5094 and the international standards ASTM D2896 and ASTM D 4739 [23–25].

The most common method of assessing the ability of engine oil to neutralize acids is the measurement of the total base number (TBN). Two methods are generally accepted for measuring reserve alkalinity: ASTM D2896 and ASTM D4739.

The ASTM D2896 standard is designed to monitor new oils, while the ASTM D4739 standard, on the other hand, is used to study the alkalinity of oils during operation to monitor additive package consumption over time.

Titration with hydrochloric acid (HCl) is carried out to determine alkalinity. Currently, the potentiometric titration method is more often used for these purposes (Fig. 2).

The titrator automatically adds 120 cm^3 of solvent (1 : 2 glacial acetic acid and chlorobenzene) to the beaker with the weighed sample and stirs it until complete dissolution. The titrant is a standard solution (0.1 mol/l) of perchloric acid $HClO_4$ in acetic acid; it is added in small portions.

If in the titration process, when adding 0.1 ml of titrant, the potential changed by more than 0.03 V (0.5 pH), then the titrant is added in portions of 0.05 ml.

The titration automatically stops when the potential changes by less than 0.005 V when adding 0.1 ml of standard perchloric acid solution in acetic acid.

The equivalence point and the corresponding to it titrant volume are determined by the electronic system of the installation and on the plot of the titration curve. The total base number is calculated automatically.

Fig. 2. Titrando 905 titrator for determining the total alkaline number of oils

Results and Discussion

The object of research in this work is the process of changing the physicochemical parameters of mineral MK-8P and synthetic Mobil Jet Oil 254 oils for turbojet aircraft engines during their operation.

The subject of the research are the two most important indicators of the quality of aviation oils, based on the results of which the anti-wear properties and the presence of the necessary additives in the oil and their effectiveness are evaluated. These are the kinematic viscosity and the total base number. Based on this, we have information on further maintenance and reliability of aviation equipment and can formulate recommendations for oil replacement. After all, the resource and reliability of engines largely depend on the correspondance the aviation oil the operational requirements of its use.

The change in oil viscosity is determined by the conditions of two mutually opposite processes: the accumulation of oxidation products, which cause an increase in oil viscosity, and the destruction of viscosity modyfiers, which leads to a decrease in viscosity. Oxidative processes usually play a decisive role during the operation of lubricating materials in machines and mechanisms.

Normative quality indicators of the mineral MK-8P and synthetic Jet Oil 254 oils are given in Table 1 [26].

Table 1

Physico-chemical properties of lubricating oils

Indicators	MK-8P	Jet Oil 254
Kinematic viscosity at a temperature of 100 °C (50 °C for MK-8P), cSt, not less	2.6 (8.0)	5.0
Kinematic viscosity at a temperature of 40 °C, cSt, no more	16.0	26.4
Kinematic viscosity at temperature of -40 °C, cSt, no more	14000	11500
Total base number, mg KOH/g, not less	0.04	0.08

The samples of Mobil Jet Oil 254 and MK-8P oils with different working hours (0, 50, 100, 150, 200, 250, 300 h) were subjected to research. The samples were analyzed for the dynamics of changes and compliance of the main quality indicators with regulatory documents. Samples of Mobil Jet Oil 254 were selected by samplers under the actual operating conditions of the Airbus H-145 helicopters. Bench tests were carried out for the oil MK-8P for turbojet engines, since it is not approved for use on helicopters.

The results of the dynamics of the kinematic viscosity of mineral MK-8P and synthetic Mobil Jet Oil 254 oils at temperatures close to those operating in the friction nodes of the mechanisms (100 °C) depending on the working time are shown in Fig. 3.

The tests results showed that the change in the kinematic viscosity of synthetic engine oil Jet Oil 254 is about 5% after 300 hours of operation in an engine. As for mineral oil MK-8P it is more than 18% after the same period of operation in an engine. Moreover, there is a more rapid increase in kinematic viscosity for mineral oil after 150 hours of operation, while no such jumps are observed for synthetic oil. This can be explained by the fact that Mobil Jet Oil 254 contains a package of additives that act comprehensively, while MK-8P contains only one antioxidant additive.

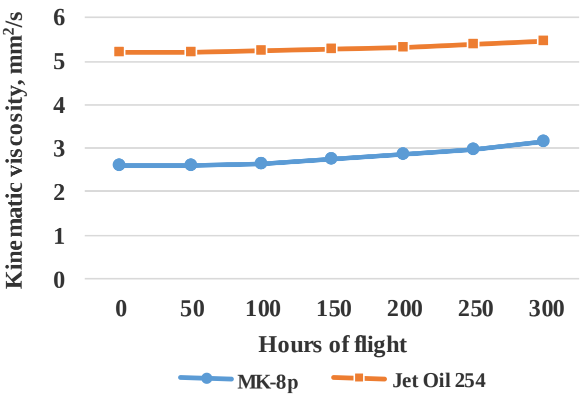

Fig. 3. The effect of oil aging on kinematic viscosity at a temperature of 100 °C

In our opinion, the main reason for the increase in kinematic viscosity is related to the accumulation of oxidation products in oils and the formation of high-molecular hydrocarbon compounds in the process of their polymerization and condensation.

It should be noted that such an increase in kinematic viscosity is not a defective indicator for both oils and is not a reason for their replacement.

Viscosity tests are carried out at different temperatures due to oil standards. The maximum allowable values at low temperatures and the minimum allowable values at high (working) temperatures are indicated.

The dynamics of the kinematic viscosity of mineral oil MK-8p and synthetic Mobil Jet Oil 254 at low temperatures (–40 °C) depending on the working time is shown in Fig. 4.

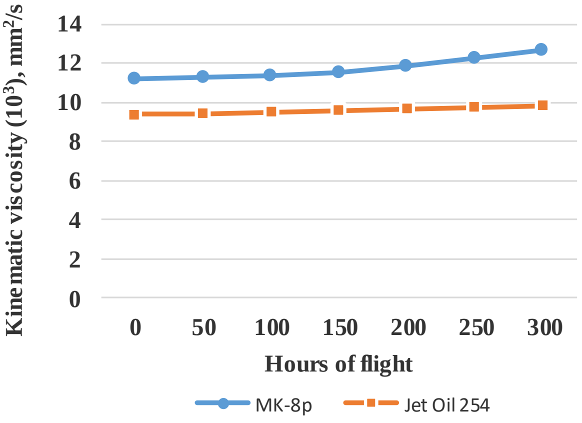

Fig. 4. The effect of oil aging on kinematic viscosity at a temperature of -40 °C

The investigation results showed that the kinematic viscosity of synthetic engine oil Mobil Jet Oil 254 depends less on temperature changes, which makes it more attractive for use in engines. This can be explained by the presence of viscosity modifyers in it.

The patterns of changes in kinematic viscosity at low temperatures for synthetic and mineral oils are similar to those at 100 °C.

The required oil viscosity depends on the type of gas turbine engine. The specific loads on the bearings are not large in turbojet engines. This makes it possible to use low-viscosity oils. Gears of helicopter reducers operate under higher contact loads. Low-viscosity oils do not stick to metal surfaces and cannot withstand high pressures, squeezing out from the contact zone. This leads to increased wear and failure of gear transmissions. Therefore, more viscous oils are needed for the lubrication of helicopter reducers. However, the use of such oils leads to difficulties when starting the engine at low temperatures, reducing the speed of changing the angle of the propeller blades. It is used to install separate lubrication systems with oils of different viscosities in order to avoid this contradiction between the viscosity of oils for lubricating engine bearings and reducers. This decision complicates the design and operation of helicopters. Airbus H-145 helicopters have a single oil system, which requires paying more attention to the quality indicators and chemical composition of the oil.

The change in the total base number of mineral oil MK-8P and synthetic Mobil Jet Oil 254 during their run-in in a helicopter engine was studied. The results of the dynamics of the total base number are shown in Fig. 5.

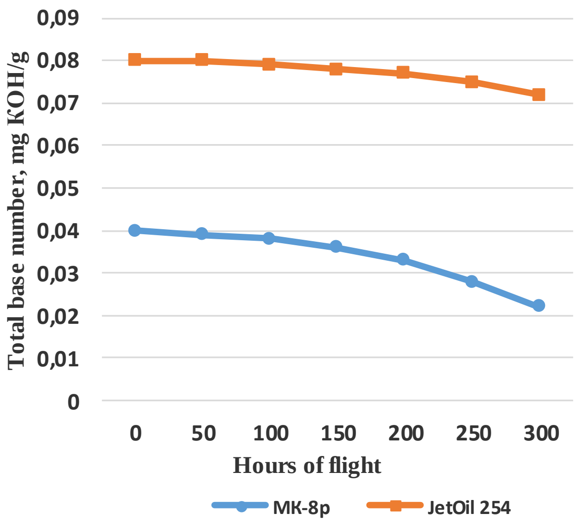

Fig. 5. The effect of oil aging on the total base number

The total base number shows the total alkalinity of the oil, including gained by detergents and dispersants that have alkaline properties as mentioned above.

It is shown that with the increase in oil aging, the alkaline number of mineral oil MK-8P drops more sharply than synthetic Mobil Jet Oil 254, which indicates the absence of alkaline additives in it.

The alkaline number inevitably decreases when the oil in an engine is working and neutralizing additives are deteriorating. Such a reducing has acceptable deviations and oil is considered to have lost its performance after reaching them. It is considered that the oil should be replaced when the decrease of alkalinity was more than 50 % from the initial value.

The dynamics of the change in total base number characterizes the rate of deterioration of additives in oils. The rate of alkalinity decrease is higher for mineral oil and the critical value is reached much faster. The synthetic oil has a significant reserve of base number at the end of experiments.

Conclusions

The working conditions of oils in helicopter turboprop engines are analyzed. It is shown that the temperature of the oil can reach over 200 °C depending on the operation modes and loads in the reducers, which leads to a change in physico-chemical and operational quality indicators and affects the terms of oil replacement.

Results of the experiments at a temperature of 100 °C showed that the change in the kinematic viscosity of the synthetic engine oil Mobil Jet Oil 254 is about 5 % after 300 hours of operation in the engine. Such change is more than 18 % for mineral oil MK-8P after the same period of operation in the engine. Moreover, there is a more rapid increase in kinematic viscosity for mineral oil after 150 hours of operation, which cannot be said about synthetic oil.

The kinematic viscosity of Mobil Jet Oil 254 synthetic motor oil is less dependent on temperature changes than mineral oil MK-8p at low temperatures (–40 °C), which makes it more attractive for use in helicopter engines and a reducer.

It has been shown that the total base number of mineral oil MK-8P decreases by almost 50 % with increasing working time up to 300 hours and drops more sharply than that of synthetic Mobil Jet Oil 254. This indicates antioxidant action and no alkaline additives.

Mineral oil MK-8P is suitable for working in separate oil systems of helicopters, namely, for lubricating turbine bearings, and it cannot be used for Airbus H-145 helicopters with a single oil system for the engine and gearbox.

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