Carbon-forming properties of oils influencing the service of engines and aircraft reducers

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Abstract. During the operation of gas turbine engines (GTE), failures are encountered due to structural, production, and operational defects. According to the damage of the gas turbine engine, the percentage of malfunctions in the lubrication and venting system is 2.9% [1]. This paper discusses the most common problematic issues in the operation of oil systems (OS) associated with the formation of solid decomposition products of oils on the surfaces of gas turbine engine parts. Laboratory studies of the creation of high-temperature carbon deposits on a heated aluminum surface were carried out by spraying the test oil on it for a specific time on the tilt plate instrument. This instrument was used to study NYCO TURBONIKOIL 98 aviation oil for aviation gas turbine engines (GTD-350, TV2-117, TV3-117, VK-2500) and main gearboxes (VR-2, VR-8A, VR-14, VR-252) aircraft (Mi-2, Mi-8T, Mi-8MTV / AMT, Ka-32). Quantitative dependencies of the formation of carbon deposits on the oil temperature and the temperature of the aluminum plate are obtained, and a color template of the intensity of formation of solid high-temperature carbon deposits depending on the oil temperature and the temperature of the aluminum plate is presented.

1. Introduction
One of the most critical elements for ensuring reliable operation and engine life is a correctly selected oil, considering the conditions of its activity in the engine oil system. The oil is a lubricating element of the engine design that simultaneously provides heat dissipation from engine hot spots while undergoing thermal, mechanical, and chemical influences that affect the quality of the oil and its ability to perform its functions for a long time and reliably.

There are many different designs of engines. However, the construction of their lubrication systems is based on a single principle. It is providing forced lubrication under pressure of the most critical and loaded bearings, gear, and spline joints, provided that the oil is reused and its residence time is reduced to reduce oil heating, saturation its air, and reduce consumption.

Typically, the operating temperature range of lubricating oils is usually characterized by the temperature of the oil at the inlet and outlet of the engine at a steady state. According to the design bureaus (DB) and equipment manufacturers, the operating temperature range for most engines is in a narrow range of 80-130°C. However, the oil temperature at the engine outlet does not reflect the exact temperatures of local oil overheating in individual friction units and may exceed it by 10-60 and more degrees [2].

The oil experiences the highest temperature loads in a turbojet engine in contact with the bearings of the high-speed shafts of the compressor and turbine (the temperature of the compressor bearings
can reach 250°C, and turbines up to 250-350°C). In turboprop engines, specific loads also have a significant effect on oil, especially in the nodes of the propeller gearbox during intensive pumping in the system [3].

A generalization of operating experience shows that the main failures and malfunctions of the lubrication and venting system during operation are [4]:

1. Increased oil consumption and, as an external manifestation, smoke, and oil leak (Fig. 1a, b, c). Possible causes of this effect are a violation of the tightness of the system due to the appearance of cracks, destruction of pipelines, or weakening of their connection.

   The consequences of a similar effect: there is a gradual decrease in pressure and an increase in oil temperature, further overheating of engine components, up to destruction from overheating of the most loaded units (bearings of the middle and rear rotor bearings, gears and bearings of the drive box) and, as a result, engine shutdown due to jamming of the rotor or disconnection of the kinematic chain of the drives.

2. Supercharging of venting system with air or hot gas of high pressure.

   Possible reasons for this effect are the destruction of the oil labyrinth seals of the bearing planes (Fig. 2a and 2b) of the rotor bearings; leaks of oil communications passing through the air or gas cavities of the high-pressure engine.

   The possible consequences of this effect: the release of oil from the system through the safety valve of the oil tank or centrifuge. Further consequences are similar to those described above.

3. Disruption of oil circulation in the system.

   Possible reasons for this effect:
   - failure (destruction) of pressure head oil pumps.

   Possible consequences of this effect: complete cessation of oil circulation, which is accompanied by a sharp drop in oil pressure to zero.

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Figure 1. The formation of solid decomposition products of the working oil due to loss of tightness of the node: a) on the details of the 2nd support of the TV3-117 helicopter engine, b) and c) on the details of the labyrinth seal of the free turbine of the TV2-117 engine.
Failure of pumping oil pumps.

Possible consequences of this effect: stopping pumping oil from the cavities of the oil system, overfilling it with oil and ejecting oil from the system;
- destruction of pressure oil communications or blockage of nozzles (nozzles) leading oil to individual nodes.

As a result of the disturbance of circulation, possible consequences may be overheating and destruction of nodes, the flow of oil to which has stopped. With the continued operation, the engine may turn off due to the overheating of the most loaded units.

2. Experimental part

The oil system operability of the power plant mainly depends on correctly selected (for the real conditions of lubrication of the friction surfaces of the engine) oil. It provides lubricity and sufficient heat removal from its units and parts during the assigned resource. The cessation and reduction of the oil supply, regardless of the cause, leads to overheating of the engine mounts, the destruction of its bearings, jamming of the rotor of the gas turbine engine until the engine turns off.

![Image](Figure 2. a) and b) Formation of solid decomposition products of the working oil on the contact seal details of the 1st support of the TV3-117 engine.)

The temperature conditions deterioration of the work of rubbing parts leads to the use in the operation of oil that does not have a margin of quality in terms of thermo-oxidative stability and has a high ability to form carbon.

For the correct selection of oil, it is necessary to conduct tests not only in the volume of the internal standard (GOST) but also by qualification methods. At the same time, the practical experience of using oils on aircraft products should be taken into account.

One of the most important properties of the oil is its ability to form soot, which directly affects the ability of the oil to remove heat and prevent local overheating as follows from the materials presented.

Previously, the organization GOSNII GA conducted studies of the carbon-forming properties of oils [5, 6]. The positive experience has been gained in producing results. However, when studying the issue of carbon-forming properties of aviation oils, quantitative standards for the resulting carbon deposits were not established under various temperature conditions of oil on a metal surface, the appearance of carbon deposits and plates was not evaluated, and accordingly, a colour intensity template was not created. In addition, over time, there have been changes associated with the advent of new equipment with more loaded units, assemblies and with an increase in the assortment of various brands of oils on the market, which affected the actual operating conditions.

Therefore, we propose an improved methodology for assessing the carbon-forming properties of oils, taking into account actual operating conditions, using NYCO TURBONIKOIL 98 as the most widely used helicopter in civil aviation in this research.

The study of the formation of solid decomposition products of aviation oil TURBONIKOIL 98 from NYCO was chosen using the method from the list of sets of methods for qualifying oils of the Interdepartmental Commission for the admission to the production and use of fuels, oils, lubricants
and special fluids under the State Standard of the Russian Federation “The tendency of oils to form high-temperature deposits "On the device" inclined plate” (GMK Decision No. 23 / 1-54 of 02/14/1979). The research was conducted on a device improved by automation.

On the “inclined plate” device, the ability of oil to form carbon is evaluated under conditions of short-term contact of the oil with a heated metal surface, which makes it possible to assess the possibility of the oil working in the lubrication system close to the actual engine operating conditions and to determine the mass amount of solid oil decomposition products at various working oil temperatures and washed parts. For this, the research conditions were expanded: the number of revolutions of the sprayer, the mode of spraying oil, the temperature of the oil, the temperature of the plate.

The essence of the method is to constantly spray heated oil onto a metal plate. The temperature of the plate is maintained at 250-350°C with a heating time of the plate for 6 hours.

As can be seen from the device diagram (Fig. 3), a roller with a metal comb of eight rows of teeth is located in the oil reservoir (2). The oil tank is situated at an angle of 25° to the horizontal. Oil in a volume of 300 cm³ from the cylinder is poured into the tank. The teeth of the roller combs are partially submerged. During operation, the roller rotates at a constant speed of 1500 ± 50 rpm. The oil splashes onto the aluminium plate at the top (1). Part of the oil lingers on the plate; part flows back into the reservoir. The temperature of the plate is maintained by an electric heater (3) located on it. The test duration is 6 hours. The oil temperature during the test is 120-180°C, the temperature of the plate is 250-350°C. The set temperature is maintained with an accuracy of ± 5°C. The amount of oil soot is determined by the weight of carbon deposits formed on the aluminium plate.

![Diagram of a device for determining solid decomposition products of oils](image)

**Figure 3.** Diagram of a device for determining solid decomposition products of oils: 1 – aluminium plate, 2 – rotating oil spray, 3 – electric plate heater.

### 3. Results and discussion

Figure 4 showing the dependence of the mass of deposits on the plate temperature for different oil temperatures, equidistant within the experimental error. The curves presented in Fig. 4 show that the mass of deposits depends significantly on the temperature of the plate.

The presenting curves (Fig. 4) show that the intensity of carbon deposits on the parts of the bearing assemblies is not directly dependent on the oil temperature in the range from 120°C to 180°C. The amount of solid oil decomposition products formed increases with increasing temperature of the plate to 350°C, at oil temperatures of 120°C, 140°C, 160°C, 170°C to 320-330°C.

The heat capacity of oil vaporisation plays a decisive role in these conditions. So, at a constant intensity of oil spraying, an increase in thermal energy supplied to the plate, upon reaching a critical value, leads to the boiling of oil droplets on the plate and the beginning of the carbonation process. The formation of a significant amount of carbon deposits (70-90 mg under the conditions of this experiment) reduces the thermal conductivity of the plate. Therefore, the amount of heat transferred to the oil decreases, and the growth of deposits slows down or completely stops according to [7]. The mass of carbon deposits is reduced because the process of "burnout" of the oil begins at a temperature of 340°C and above.
In the process of studying the dynamics of the formation of solid decomposition products of NYCO TURBONICOIL 98 aviation oil, a regular change in the appearance and physical properties of carbon deposits was established depending on various temperature conditions. In fig. 5 are photographs of carbon deposits obtained on aluminium plates.
It was noted analysing the data obtained that at a plate temperature from 250°C to 270°C, a thin layer of deposits is formed in the form of varnish. It has a smooth, shiny surface of light yellow and brown colour. With increasing temperature of the plate from 280°C to 350°C, the nature of the deposits changes from an even thin layer to a matte one. With increasing temperature of the plate above 300°C, deposits become thin black soot and black with interspersed carbon particles, which give some surface roughness and the formation of a glossy black surface in the upper part of the plate.

4. Conclusion
It can be concluded based on the work carried out that the materials obtained will make it possible to predict the ability of the oil to perform its functions for a long time and reliably protecting the engine components and assemblies from overheating and, accordingly, to ensure reliable operation and engine life under various temperature conditions of its service.

In our opinion, it is advisable to continue the work on the accumulation of materials for a comparative assessment of the characteristics of carbonisation and the formation of solid decomposition products of various oils. The results obtained can be useful in the development of engine modes, the selection of new and modified oils with the introduction of unprincipled changes in the previously adopted production technology, for periodic verification of commissioned oils that have already been put into operation, as well as for the development of an active program of measures to eliminate failures.
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