PRINCIPLES AND EXPERIENCE OF THE ON-CONDITION APPLICATION OF OILS AND WORKING FLUIDS TO AERONAUTICAL ENGINEERING

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Abstract: With dvances in technology, increasingly important become the operational properties, consumption, cost and shortage of oils, working fluids (subsequently referred to as oils) as well as the role of oil parameters as diagnosis indications for an "oil-machinery" system as a whole. Hence it follows that the man-hours required for maintenance and improvement of ecological situation near machinery operation sites should be reduced.Especially important is the problem regarding aircraft (AC), which is associated with elevated requirements to their reliability and operational safety. The analysis of the problem has shown that the major way to its solving is the creation and implementation of a methodological and information-analysis base providing the on-condition oil application in place of scheduling oil changes and, as a consequence, the more complete realization of oil quality potential in service. The paper is prepared based on the analysis of the results of multiyear investigations of oil properties in the course of their accumulation for machinery of various types, mainly aeronautical engineering, and their diagnosing. It is the continuation of works presented previously at analogous conferences held in Swansea (England), Buenos Aires (Argentina),Pensacola (USA) [1-3].

Key Words: Oil; fluid; application; condition; operation; destruction; oxidization; viscosity,

Investigations and implementation of the on-condition working-fluid application to AC's hydraulic systems: A purposeful investigation of working-fluid properties under operational conditions in AC's hydraulic systems has shown the possibility of implementing the principle of their on-condition application instead of scheduling their changes (every 200-250 hours).In so doing, it was found that a decrease in kinematic viscosity of AMГ-10-type fluids, containing a stiffening components, takes place. The duration and the allowable level to which the viscosity decreases under the conditions existing in a hydraulic system, and consequently, the service life of a working fluid are dependent on the intensity with which various factors affect the fluid causing the mechanical destruction of a stiffening polymer and influencing destruction kinetics. Despite the fact that oxidization processes occur in the fluid accompanied by the accumulation of oxidization products increasing the acid number, the condition of the AMГ-10 hydraulic fluid is dominated by destructing the stiffening component and decreasing its viscosity.

This conclusion is supported by the experiment conducted on the simulation facility (pump rig) and ultrasonic instrument with variable actions (pressure 21 MPa, test duration up to 50 hours, fluid volume $18 dm^3$, temperatures 125 and 150°C - the maximum allowable for the AMГ-10 fluid; the ultrasonic action was exerted during 1 hour). As for synthetic hydraulic fluid 7- 50c-3 containing no stiffening agent, its condition was dominated by the accumulation of oxidization products. In so during its acid number increased and viscosity increased a little. An increase in the intensity of mechanical action upon the AMГ-10 fluid due to increasing pump speed from 2900 to 4000 r.p.m. resulted in decreasing fluid viscosity by 10-15% relative to its initial level accompanied by a minor variation in acid number. Replacing nitrogen with air in the experiment led to augmenting the oxidization process in the fluid and increasing its acid number by a factor of three.

With ultrasinic action an increase in oscillation amplitude from 40 to 65 mk resulted in sharply amplifying mechanical destruction of the polymer stiffener (fluid viscosity decreased by 30-40%). From the aforesaid it follows that parameters of hydraulic fluids in AC's systems differ from their initial levels and the main task is to establish allowable levels of governing paramrters for concrete "fluid-AC's hydraulic unit" system and introduce their operational monitoring. Thus we have worked out the following list of governing parameters and their allowable levels (Table I).

Table I. Governing parameters of working fluids for AC's hydraulic systems and their allowable values

Parameter	Working fluid, allowable/standard values			
	AMГ-10	MГE-10A	7-50c-3	Non-flammable hydraulic fluid
Kinematic viscosity at 50°C, cSt	7 / 10	7 / 10	17-26 / 22 at 20°C	6 / 8.7
Acid number, mg KOH/g, no more than	0.015 / 0.05	0.9 / 0.4-0.7	0.8 / 0.1	0.2-0.3/ 0.08
Fraction of mechanical additives and water, %, no more than	0.005 / 0.003	0.005 / 0.003	0.005 / 0.002	According to documents
Time to stabilize governing parameters	30-40	40-50	60-80	60-80

As current parameters reach the values indicated in Table 1, the fluid in a hydraulic system should be replaced with the fresh one. This rule of using hydraulic fluids is now introduced throughout the aircraft fleet in Russia, which has provided a 2-3 times reduction in their operational consumption.

A methodology was craeted ensuring the on-condition use, regeneration and reuse of fluids in AC's hydraulic systems including their cleaning, recovering the parameters deviated beyond the allowable limits. The methodology uses a complex system incorporating the computer-aided processing of information and reference data.

Investigation and implementation of the on-condition oil application to aircraft engines: Based on the analysis of normally operating "oil-AC's engine" systems during scheduled period before oil change, the following main indications for implementing the on-condition oil application were established: continuous circulation and contact of a limited oil volume with oil system parts; accumulation in the oil of the information and diagnosis indicators of the condition of the system as a whole; refreshment of oil quality with fresh oil during machinery operation.

In destincton to the joint USA program JOAP, in Russia the activities in this field are carried out according to purposeful programs, the most successful of them is realized in aviation. In pursuing these aims, put in operation is the network of laboratory and rig centers destined for testing petroleum products, assessing and monitoring their parameters, including Petroleum Product Test and Sertification Centers under Russian State Standard Committee.

The implementation of the methodology for the on-condition oil application in technical equipment is a complex of long-term, time-consuming and expensive measures, among them there are: analysis of operating conditions, substantiation of the list and levels of acting factors for concrete "oil-engine" systems as well their functional and governing parameters; forecasting the regularity of variations in oil properties, establishing allowable levels of parameters, methods and means for monitoring them during operation; choice of aeronautical equipment, development of programs and directions aimed at conducting test work in various stages; esrablishing the rules for assessing the condition of technical equipment, oil, oil systems in operation; taking decisions regarding the ahead-of-schdule oil changes and stoppage of equipment operation (if necessary); removing the monitored engine from service, supervision of defects in the engine's oil system and transmission parts at repair works; drawing up a conclusion based on the results of the investigation.

Taken as governing parameters can be those relating to both the oil and the equipment but provided that the parameters define the reliability of a system as a whole. The analysis of the results of investigation has shown that the products of wearing can not alwais be considered as dominating factor in comparison to oil quality parameters associated for example with oxidization and destruction processes in oil components and oil foaming.

Such parameters as viscosity, acid number, flash point, and filterability can turn out to be more sensitive and making it possible to obtain the information about the predicted condition of the "oil-engine" system elements earlier than the information about the concentration of wearing products in the oil.

For the oils usable in aircraft engines a list of governing parameters and their allowable levels was established (Table II) on exceeding of which the oil should be changed with the fresh one.

Table II. Governing parameters of oils for their on-condition application to aircraft engines and their allowable values

Oil specification	Governing parameters, allowable/standard values				Time to stabilize parameters, hr.
	Kinematic viscosity, cSt, at temperature: $50^0 C$	$100^0 C$	Acid number, mg KOH/ g	Wearing products, g/t	
МС-8п	10.0 / **8.0**	-	1.0 / 0.05	5.0(Cu) 6.0(Fe)	50-60
МС-8рк	11.0 / **8..0**	-	1.0 / 0.15	5.0(Cu) 6.0(Fe)	50-60
ИПМ-10	-	5.5 / **3.0**	4.0 / 0.05	4.0(Cu) 6.0(Fe)	80-90
ВНИИ НП-50-1-4ф (ВНИИ НП-50-1-4у)	-	5.5 / **3.2**	3.5/0.22 (0.25)	-	80-90
МН-7, 5у		**6.6**; 11.0/7.5	- / 0.1	-	100-120
Б-3в	-	6.2 / **3.0**	2.0 / 4.4	-	-
ЛЗ-240	-	6.2 / **4.8**	2.0 / 5.0	-	-

Note: bold type - " not less", other - " not more"

Given in Table III are the data on implementing the on-condition application of oils to aircraft engines.

Table III. Data on implementing the on-condition application of oils to AC's engines.

Engine	**Oil (base)**	**Number of oil changes in engine**	**Time between oil changes, hr**		
			Primary	**Intermediate**	**Established**
For 1- and 2-engined AC	Petroleum	4-6	50-100	200	On-condition
	Synthetic	4-6	100	300	- " -
For 3- and 4-engined AC	Petroleum	5-6	300	600	- " -
	Synthetic	5-6	600	1500	- " -
For cargo ang assenger AC	Petroleum	3-4	200	600	- " -
	Synthetic	3-4	300	600	- " -
For trainer AC	Petroleum	3-4	300	500	- " -
	Synthetic	-	-	-	
For helicopters	Petroleum	3-4	one year	two year	- " -
	Synthetic	3-4	one year	two year	- " -

The implementation of such an approach has enabled a 2-3 times reduction in oil consumption and provisions for other advantages.

Assessment of the possibility for applying the oil Turbonicoil-210A of the French company Nico to Russia-produced aircraft engines: Currently accomplished in Russia are the measures and investigations on a comparative assessment of the qualities of domestic and foreign oils, lubricants and special fluids, on estimation of the possibilities of the application of these products to Russian aircraft engines, on the adaptation of the procedures and means for testing and monitoring the quality of petroleum products during their direct use and on establishing business contacts with corresponding companies.

This is justified by searching alternative foreign oils in connection with exporting Russian aeronautical equipment of civil and military purpose and by the need for covering the deficit of main oils at Russian internal market, as well as by other factors.

It turned out that the oil analogues produced by the French company Nico are the most compositionally and qualitatively close to the main Russian oils. According to our evaluations, the oils of this company are also the most acceptable from technical, economic and cost considerations.

Thus, investigations have shown that the polyisoolefine-acid-based Turbonicoil-210A oil (TH-210A) is practically a full analogue for the isoparaffinic oil ИПМ-10 basically used in highly heat-loaded engines, including the complex of additives and agents.

According to the results of qualification tests, the oil TN-210A features the higher levels of thermal stability (up to 200°C) and foaming resistance with practically equivalent physical and chemical properties, which facilitates the adaptation of monitoring techniques and means used in laboratory, rig and operation testing of this oil under Russia's conditions.

At present together with the French party we are treating a question regarding the full-scale operational tests and introduction of the oil in highly heat-loaded engines of maneuverable AC interchangeably with Russian oils. It is planned to implement the complex of works and investigations according to Russia-accepted methodology for the on-condition application of this oil to AC's engines.

Some theoretical aspects of the on-condition application of oils and fluids: The methodology of the on-condition oil application is based on the substantiation of a functional interconnection between oil and equipment parameters, which enables an "oil-equipment" system to be considered as an interconnected object. This interconnection within an "oil-equipment" system is represented in the columns of Table IV.

Note to the table IV: F_{op} and F_s are respectively the operational and structural factors; t is the temperature, p is the pressure; P_v is the vibration parameter; Q_s is the supply amount (volume); R_s is the supply rate; I_f is the filterability index; t_s is the solidification temperature; ν_t is the current kinematic viscosity; ψ is the ambient humidity; q_d is the deposition amount; K is the acid number; R_w is the wearing rate; C_{wp} is the wearing product concentration; φ is the friction coefficient; $I_c(R_c)$ is the corrosion index (rate); t_f is the temperature foam formation.

Table IV. Interconnection within an "oil-equipment" system.

Process in the equipment	Oil operational property	Factors acting in the system	Functional parameters		Governing parameters
			Equipment	Oil	
Supply	Destruction of oil components	$F_{op}(t;p;P_v)$	$Q_s;R_s;I_f$	$t_s;I_f;\nu_t$	$Q_s;R_s;\nu_t$
Circulation ability	Structural and mechanical stability	$F_{op}(p;t;\psi_0)$ F_s	$I_f;Q_s$	$\nu_t;t_f$	$Q_s;\nu_t$
Oxidization of oil components, depositation and sedimentation in engine	Physical and chemical stability	$F_{op}(t;\psi;\varphi)$; F_s	$I_f;q_0$	$K;I_f$	$I_f;q_d;K$
Wearing	Wear-resistant properties	$F_{op}(p;t)$; F_s	$R_w(C_{wp})$; φ_t	$R_w(C_{wp})$; φ_t	$R_w(C_{wp})$; φ_t
Corrosion	Corrosion-resistant properties	$F_{op}(p;\psi)$ F_s	$I_c(R_c)$	$I_c(R_c);K$	$I_c(R_c)$

The "oil-engine" system is categorized as the complex and multifactor one. The solution of system optimization problems is aimed at the substantiation of the system governing perameter (P_{op}) and determination of its allowable level in operation according to relationship (1):

$$P_{op}=f(F_{op};F_s;F_e;P_f), \qquad (1)$$

where F_e is the oil operational properties factor; P_f is the system functional parameter.

The model of the "oil-engine" system (Table IV) is the basis of the methodolody of the on-condition oil application which is implemented in accordance with the following principles: establishing interconnections inside concrete systems (factors and functional parameters); substantiation of a governing system parameter and its allowable value for operational conditions; technical and economic evaluation of the effectiveness of oil application to the engine.

This approach is illustrated in Fig. 1 where the operational region is shown for kinematic viscosity of the oil MH-7.5y ranging from 6.6 to 11.0 cSt with an initial level of 7.5 cSt. The oil is applied to two engines of different types. In this case, dominating in the engine of the first type are the loads causing the destruction of oil components, whereas operational conditions of the engine of the second type are dominated by the temperatures at rear engine bearings, which is accompanied by intensifying oxidization processes and leads to accumulating oxidization products and increasing the oil viscosity. The problem is solved on establishing allowable values of the MH-7.5y oil viscosity: it should be no less than 6.6 cSt for the engine of the first type and no more than 11.0 cSt for the engine of the second type. In cases of oil viscosity being beyond the limits indicated, the oil is to be changed with the fresh one.

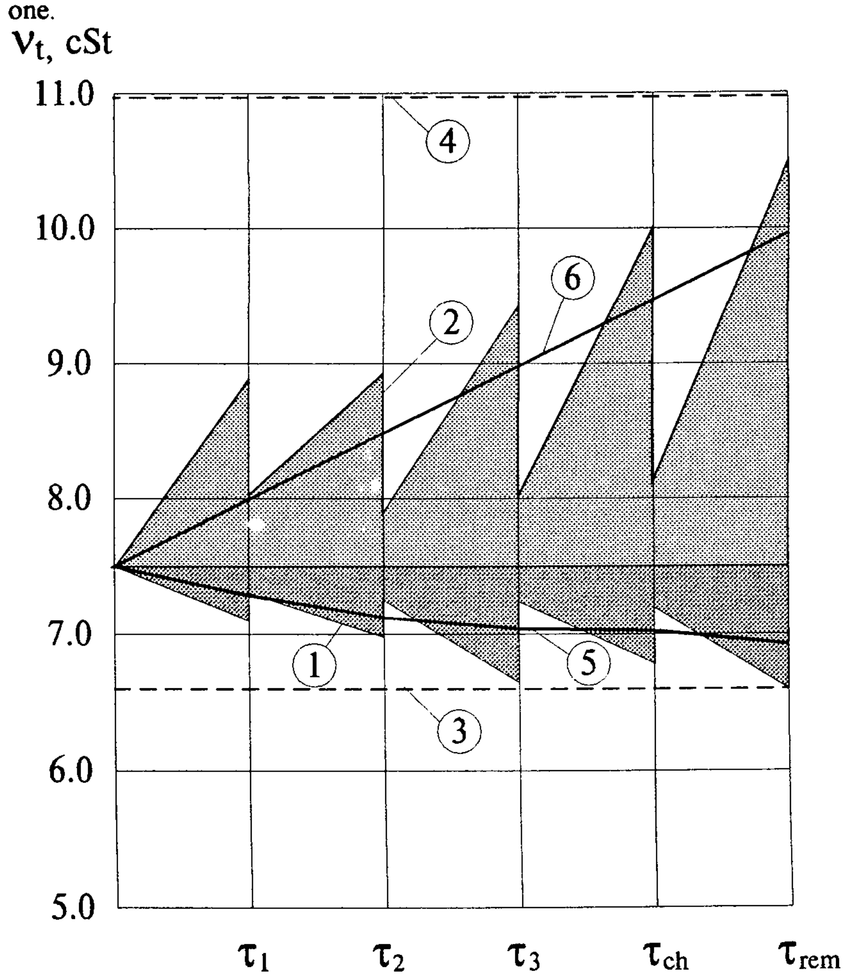

Fig. 1 Dynamics of varying the MH-7.5y oil kinematic viscosity taken as the governing parameter in the engines of the first (1) and second (2) types

Note to the figure 1: In-service time of an engine expressed in periods of maintenance monitoring and reoiling is $\tau_1, \tau_2, \tau_3 \cdot\cdot \tau_{ch}$; τ_{rem} is the time for engine removal).

1 , 2 - bounds of the working range of viscosity variation providing reliable operation of the engines of the 1st and 2nd types; 3 , 4 - allowable viscosity levels for the oil applied to the engines of the 1st and 2nd types, respectively; 5 , 6 - design viscosity variations of the oil when applied to the engines of the 1st and 2nd types, respectively.

The following design formulas for determining current viscosity values of the oil MH-7.5y in its application to above indicated engines were obtained:

for the 1st engine $$\nu_t = 7.5 - 0\ 001\tau + 2.337 \cdot 10^{-7} \tau^2 \quad (2)$$

for the 2nd engine $$\nu_t = 7.5 + 0.01\tau + 6.3 \cdot 10^{-6} \tau^2 \quad (3)$$

Transition to definite steady levels of oil properties in the course of its use in techincal equipment is most likely associated with structural and energetic mutual adaptation of the elements of tribomechanical systems.

With a definite combination of phases, operational conditions and structural features of a system and with accounting for repetitive fresh-oil replenishment in operation, current steady-state mode, featuring system self-adjustment, takes place. It allows a conclusion to be made that with a partial oil changes the tribosystem is a less long-run one because it operates in a nonlinear mode characterized by fluctuating oil properties from where follows the feasibility of the current self-adjusting system stabilization mode.

The realization of self-adjustment mode of operation of various "oil-engine" systems is supported by the results of numerous investigations and conclusions on a two-stage variation of the parar eters of systems elements: short-duration evolution of their properties (operating time of 40-1_0 hours) and long-dura on transition to a steady node (well over 60-120 hours). This is also confirmed by the results of testing on simulation facilities with imita n of the operation of actual aircraft units and subassemblies. For every "oil-engine" system the stages of the evolution of oil properties and their adaptation should be established. It is of importance therewith to exclude from changing the oil in the stage of the evolution of its properties.

At present we are implementing this approach in aviation.Involved in this process are aircraft industry works, research and servicing organizations, and created under the Russian State Standard Committee are the special test and certification centres each oriented to a certain type of machinery and associated oils and hydraulic fluids.

Conclusions: 1. Established and implemented on the basis of experimental and theoretical investigations is the possibility of the on-condition application of oils and working fluids to aircraft systems in place of schediling their changes, which has enabled a 2-3 times reduction in oil consumption and other operating costs, diagnosing oils' and systems' condition in operation. Such an approach makes it possible to correct perameters of oils during their production.

2. It was found that the implementation of the on-condition oil application to aircraft engines

is based on the adaptation of oil properties to engine operational conditions and the associated necessity for establishing the interconnection between factors and functional parameters within concrete "oil-engine" systems and the stages of evolution and stabilization of oil properties, which permits excluding draining the oil from technical equipment when its quality potential is not exhausted yet.

3. The possibility is demonstrated of the application of the oil Turbonicoil-210A of the French company Nico to Russia-produced aeronautical engineering.

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