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IMPROVING METHODS FOR MONITORING BEARING UNITS OF ELECTRIC MOTORS IN REVERSE WATER SUPPLY SYSTEMS OF NUCLEAR POWER PLANTS

С. Зайцев, В. Тіхенко. **Вдосконалення методів контролю підшипникових вузлів електродвигунів у системах зворотного водопостачання атомних електростанцій.** Забезпечення надійності та безпеки атомних електростанцій є актуальним завданням для енергетичної галузі України. Для змащування поверхонь тертя у підшипникових вузлах електричних двигунів водних насосних агрегатів градирень систем охолодження необхідна постійна циркуляція мінеральної турбінної олії, контроль стану якої може вказувати на наявність дефектів обладнання під впливом різних чинників. Підвищення надійності оливонаповненого обладнання атомних електростанцій може бути досягнуто за рахунок визначення в турбінних оливах вмісту розчинених газів; присадки «Іонол»; механічних домішок із визначенням їх типу. При виконанні досліджень застосовано методи газової хроматографії для визначення вмісту розчинених газів та присадки «Іонол» в турбінних оливах. Для турбінної оливи та суміші «вода в турбінній оливі» досліджено фізико-хімічні та теплофізичні властивості – густина; температура спалаху; кінематична в'язкість; кислотне число; вміст механічних домішок, води, присадки «Іонол». Досліджено залежності концентрацій розчинених газів в турбінній оливі та в суміші «вода в турбінній оливі» від температури, а також характер дії акустичної кавітації на кінематичну в'язкість оливи та генерування розчинених газів. Метою роботи є підвищення надійності енергетичного обладнання атомних електростанцій за рахунок удосконалення контролю фізико-хімічних та теплофізичних властивостей мінеральної турбінної олії марки «Тп-30» системи циркуляційного забезпечення оліями підшипникових вузлів електричних двигунів водних насосних агрегатів зворотного водопостачання атомних електростанцій.

Ключові слова: турбінна олива, насосний агрегат, градирня, розчинені компоненти, газова хроматографія

S. Zaitsev, V. Tikhenko. **Improving methods for monitoring bearing units of electric motors in reverse water supply systems of nuclear power plants.** Ensuring the reliability and safety of nuclear power plants is an urgent task for the Ukrainian energy industry. Permanent circulation of mineral turbine oil is necessary for lubrication of friction surfaces in bearing units of electric motors of water pumping units in cooling systems. Monitoring its condition can indicate the presence of equipment defects under the influence of various factors. Increasing the reliability of oil-filled equipment of nuclear power plants can be achieved by determining the content of dissolved gases in turbine oils; additives "Ionol"; mechanical impurities with the determination of their type. The content of dissolved gases and additives "Ionol" in turbine oils was determined by gas chromatography methods. For turbine oil and a mixture of "water in turbine oil" the physico-chemical and thermophysical properties were investigated – density; flash point; kinematic viscosity; acid number; the content of mechanical impurities, water, additives "Ionol". The dependences of the concentrations of dissolved gases in turbine oil and the "water in turbine oil" mixture on temperature, as well as the nature of the effect of acoustic cavitation on the kinematic viscosity of the oil and the generation of dissolved gases, have been studied. The aim of the work is to increase the reliability of power equipment of nuclear power plants by improving the control of the physicochemical and thermophysical properties of mineral turbine oil of the brand "Tp-30" of the circulation system for supplying bearing oils with electric motor units of water pumping units of reverse water supply of nuclear power plants.

Keywords: turbine oil, pumping unit, cooling tower, dissolved components, gas chromatography

Introduction

Electric motors are used in the heat exchange equipment of the Ukrainian NPP power units to ensure reliable operation of the water return pumping units during the operation of evaporative cooling towers [1]. The circulation systems of mineral turbine oil (hereinafter referred to as MTO) in the bearing units of electric motors provide the established levels of reliability indicators during the operation of such pumping units [2, 3]. These MTOs can also be used as an information environment in which the presence of diagnostic components (dissolved gases; water; additive "Ionol"; mechanical impurities) characterizes the existence of equipment defects in the zones of friction surfaces. For example, defects in the bearings in the electric motors of water pumping units of reverse water supply under the influence of point exposure to high temperatures, electric currents, vibration. Damage to the electric motors of recycled water pumping units during the operation of evaporative cooling towers can lead to emergencies during the operation of nuclear power plants. Sources of water ingress into MTO can be MTO coolers of the "MTO – cooling water" type of the NPP equipment cooling system [1]. Experimental studies of the physic and chemical as well as thermophysical properties of MTO in the course of their operation make it possible to diagnose pumping units of reverse water supply during the NPP operation evaporative cooling towers using the appropriate diagnostic models.

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Analysis of recent research and publications

In work [4], when determining the thermophysical properties of refrigeration oils, a block diagram for providing these processes is proposed, which can be improved and used to determine the physicochemical and thermal properties of MTOs. Currently, it is proposed to use the method of electropulse determination of MTO humidity [5], but this method is not fully applicable to the determination of water concentration in MTO mixture containing undissolved air. Methods for determining the content of mechanical impurities in insulating oils are given in the work [6]. Methods of determining the antioxidant additive “Ionol” in mineral oils are given in works [7 – 10], including by methods of infrared spectrometry, gas chromatography (GCh). These methods can also be applied to MTO. In bearing lubrication systems in MTO, it is possible to generate dissolved gases H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO, CO_2 (hereinafter – dissolved gases) as a result of the flow of tribochemical reactions, including due to vibrations with the occurrence of a cavitation regime and the flow of sonochemical reactions [10, 11]. In bearing assemblies in the zone of limit friction, the temperature can reach 400 °C and higher, which leads to the melting of babbitt, its mechanical destruction and decomposition of MTO with the generation of solid, liquid and gaseous products of this decomposition [12]. The works [13, 14] provide information on the generation and methods of determining the content of dissolved gases H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO, CO_2, O_2, N_2 in mineral transformer oils, which were determined by GCh methods [15, 16, 17]. The method of determining the effect of temperature or acoustic cavitation on the generation of dissolved gases H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO, CO_2 in mineral insulating oils is considered in the paper [18, 19, 20]. In works [21, 22], the influence of the operating modes of MTO circulation support systems on the condition of the equipment of turbo-units and pump units, including during hydrogen wear of the metals of the bearing units, was investigated.

It was shown in [23] that with a thermal defect in the temperature range from 150 °C to 300 °C, saturated hydrocarbons are preferentially formed in mineral insulating oils, requiring minimal energy for their formation. For the pyrolysis of mineral olives at such temperatures, the key gases are H_2, CH_4, C_2H_6, C_3H_8, C_3H_6, C_4H_8. Due to temperature changes, the amount of C_2H_4 is increasing. At the same time, the rate of formation of all these gases because of the destruction of mineral oil, if the thermal defect develops, will constantly increase due to the convective transfer of new portions of oil to the zone of the thermal defect. In [10], a method for determining the water content in mineral transformer oil is considered, which includes the following measuring operations. The test oil product is heated in a flask with a refrigerator in the presence of an immiscible solvent with water, which is distilled together with water, which is in the analyzed sample. The condensed solvent and water are constantly separated in the trap, with the water remaining in the graduated compartment of the trap and the solvent returning to the distillation vessel (flask). This method requires a lot of time for its implementation and the use of complex equipment and toxic solvents. In [24] it is indicated that when determining the water content in mineral transformer oil:

a) when using the coulometric titration method with K. Fischer's reagent, this reagent interacts with the oxidation products (organic acids, alcohols, phenols) of mineral transformer oil, which distorts the results analysis, overestimating it;

b) analyzing degassed mineral transformer oil using calcium hydride (CaH_2) may give underestimated results due to dissolving some of the gaseous H_2 formed in the mineral transformer oil and obtaining a $Ca(OH)_2$ film on the surfaces of CaH_2 particles, blocking the surface of these particles and not allowing the chemical reaction to proceed to the end ($CaH_2 + 2H_2O = Ca(OH)_2 + 2H_2$).

In [3], a method for determining the presence of water in energy oils is given, according to which, when energy oil is heated to a temperature of 150 °C. The water contained in it will form foam, crackle and cloudiness of this oil. According to these signs, the presence of water in this oil is judged. However, this method is qualitative and does not determine the amount of water in energy oil. Methods for determining the water content in mineral energy oils based on the results of GCh analyzes do not have such shortcomings [24, 25]. It was shown in [26] that, under the conditions of oil hydrocracking, sulfur, oxygen, and nitrogen compounds are converted with the formation of H_2S, H_2O and NH_3 from them. The same processes can also occur during MTO hydroracking. It is stated in [17] that the determination of the content of dissolved gases H_2S, SO_3, NH_3, which accumulate in mineral power oil under the influence of electric and thermal fields on it, makes it possible to obtain additional information about emerging defects in oil-filled power equipment. This allows, in turn, creating new diagnostic models. Therefore, at a temperature of 300 °C and above, mineral transformer oil, which contains sulfur compounds, decomposes with the accumulation of H_2S and COS in it. These substances are able to participate in the chemical corrosion of structural materials made of non-ferrous metals and form electrically conductive colloidal particles in the volume of transformer mineral oil. At the same time, the determination of the content of H_2S and COS in mineral transformer or turbine oils containing sulfur compounds can be used to identify a thermal defect in OFPE with a temperature in the defect zone of 300 °C and above. The results obtained in works [2 – 26] can be applied to MTO. In [27], the problems that arose because of an emergency shutdown of the pumping unit of the evaporative cooling tower in the Rovno NPP are considered. This shutdown was associated with defects in bearing assemblies with circulating MTO lubrication and led to a sharp increase in the temperature of the thrust bearing segments of the electric motor of the water pump unit. In turn, this led to the implementation of repair work and measures to ensure the reliability of power equipment by improving the control of the physicochemical and thermophysical properties of MTO of the “Tp-30” brand in the reverse water supply system for NPP cooling towers. Thus, for NPPs, it is necessary to constantly improve the reliability of power equipment with a water-cooled power reactor by improving the monitoring of the state of operational MTO (hereinafter – OMTO).

The purpose of this work is to increase the reliability of NPP power equipment by improving the control of the physico-chemical and thermophysical properties of the “Tp-30” OMTO system for oil circulation in the bearings of electric motors of NPP water pumping units.

Research objectives:

1. To investigate such physical-chemical and thermophysical properties of fresh MTO and OMTO as: density; flash point in an open crucible; kinematic viscosity at t = 40 °C; acid number; the content of mechanical impurities; water; “Ionol” additive; dissolved gases (H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, C_3H_8, C_3H_6, C_4H_8, H_2S, CO, CO_2, O_2, N_2).

2. Investigate the nature of the temperature effect in the range from 15 °C to 80 °C on the solubility of H_2 in OMTO, previously saturated with air.

3. To investigate the nature of the temperature effect in range from 20 °C to 350 °C on the generation of dissolved gases H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, C_3H_8, C_3H_6, C_4H_8, H_2S, CO, CO_2 in OMTO and in the mixture “water in OMTO”, which pre-saturated with air. 4. To investigate the nature of the effect of acoustic cavitation on:

a) the generation of dissolved gases H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, C_3H_8, C_3H_6, C_4H_8, H_2S, CO, CO_2 in OMTO and in the mixture “water in OMTO”, previously saturated with air;

b) density and kinematic viscosity of OMTO.

Presentation of the main material

When performing the research, samples of liquid media were used: fresh MTO (content of sulfur compounds up to 0.8 % mass [10]) and OMTO brand “Tp-30”; grading mixtures of components (dissolved gases H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, C_3H_8, C_3H_6, C_4H_8, H_2S, CO, CO_2, O_2, N_2; “Ionol” additives; water) in OMTO; mixture “water in OMTO”. The investigated physical-chemical and thermophysical properties of fresh MTO and OMTO are following: density ρ; flash temperature in an open crucible t_0; kinematic viscosity at a temperature of 40 °C; acid number AN [2, 3]; the content of mechanical impurities X_m [2, 3, 6]; water content W [2, 3, 10]; the content C_i of the additive “Ionol” [8]; content of C_g dissolved gases [28, 29]; solubility characteristics X_i for H_2 [10].

The “Krystal-2000M” chromatograph was used to determine in OMTO the content of C_g (ppm) of i-th dissolved gases H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, C_3H_8, C_3H_6, C_4H_8, H_2S, CO, CO_2, O_2, N_2 (detection thresholds according to the requirements [28, 29, 30]), “Ionol” additives C_i (% mass), threshold for determining $C_{i,\min}$ = 0.05 % mass. The “LHM-80” chromatograph was used to determine the water content W (g/t) in OMTO, the threshold for determining the water content $C_{w,\min}$ = 2 g/t [10]. When investigating the nature of the effect of temperature on the solubility of gaseous H_2 in OMTO (dissolution of H_2 in OMTO), experiments were performed for 8 hours in syringes with a volume of 20 cm^3 at temperatures of 15...80 °C according to the method [10] using a UT-15 thermostat. When studying the nature of the temperature influence on the generation of dissolved gases H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO, CO_2, H_2S in OMTO and the “water in OMTO” mixture (pre-saturated with air) for 150 h [18], the following were used airtight glass syringes volumes of 20 cm^3 each and thermostat FED-53 (E2) for temperature studies in the range of 20...180 °C; hermetic stainless steel metal containers with a volume of 30 cm^3 each and a SNOL-67/350 thermostat for temperature studies in the range of 250...350 °C.

When studying the nature of the effect of acoustic cavitation on OMTO samples and “water in OMTO” mixtures (pre-saturated with air): the ultrasonic (US) device “Mermaid” was used with irradiation frequencies in the range of 35...125 kHz and the power of the US emitter 40 W, taking into account recommendations [31, 32]; the initial concentration of water in the “water in OMTO” mixture had a value of C_w = 450 mg/dm^3. When studying the content of X_m mechanical impurities in OMTO, “Millipore”-type membrane filters with a diameter of 47 mm and pores with a size of 1.2 μm were used to determine the type of pollution, as well as an MSH-50 microscope. When studying the effect of temperature or acoustic cavitation on the generation of dissolved gases H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, CO, CO_2, H_2S in OMTO and the “water in OMTO” mixture, installations were used, the principle of operation of which is shown in the paper [10].

When developing methods for preparing OMTO samples and the “water in OMTO” mixture for determining physico-chemical and thermophysical properties:

a) when determining the nature of the effect of temperature on the solubility of H_2 in operational OMTO, these OMTO is preliminarily dried with silica gel to a water content of no more than 2 g/t and degas to a final total content of dissolved gases of no more than 1000 ppm;

b) when determining the nature of the influence of temperature or acoustic cavitation on the generation of dissolved gases in OMTO, these OMTO are pre-dried with silica gel to a final water content of no more than 2 g/t and degassed to a final content of dissolved gases (no more): 2 ppm – for H_2; 0.5 ppm – for C_2H_2; 1 ppm – for each of the gases CH_4, C_2H_6, C_2H_4, C_3H_8, C_3H_6, C_4H_8; 5 ppm – for each of the CO, CO_2 gases; after degassing, OMTO samples are saturated with dry air at a temperature of 20 °C;

c) when determining the nature of the effect of acoustic cavitation on the generation of dissolved gases in “water in OMTO” mixtures: OMTOs are pre-degassed to the final content of dissolved gases according to the above point “b”; after degassing, the required amount of water is added to the OMTO sample; the obtained mixtures are saturated with dry air at a temperature of 20 °C;

d) when determining the nature of the effect of acoustic cavitation on the density and kinematic viscosity of OMTO, this OMTO is pre-dried with silica gel to a water content of no more than 2 g/t.

Results

When examining the damaged bearing assembly of the electric motor of the water pump unit of the cooling tower of the Rovno NPP, a sharp increase in the temperature of the pump motor bearing segments was revealed. In addition, the failure of the “oil wedge” between the fifth pump and the thrust bearing segments at a temperature of 57 ° C when using OMTO for lubrication and cooling. The babbit insert is partially mechanically destroyed with the formation of metal particles of different sizes; there is a local partial melting of the metal of the babbitt lining. The motor shaft in the bearing assembly has signs of mechanical and thermal defects [27].

1. When studying the physico-chemical and thermophysical properties of fresh MTO and OMTO, it was established that:

a) indicators of the quality of fresh MTO correspond to established standards [2] and have the following values: density ρ = 0.895 g/cm^3; flash temperature in an open crucible t_0 = 18 °C; kinematic viscosity v = 46.2 mm^2/s at temperature 40 °C; acid number AN = 0.024 mg of KOH per 1g of MTO; the content of mechanical impurities X_m = 0.0026 % mass; water content W – absence (W < 0.03 % mass); “Ionol” additive content S_i = 0.73 % mass;

b) quality indicators of OMTO correspond to established standards [2, 3] and have the following values: density ρ = 0.898 g/cm^3; flash temperature in an open crucible t_0 = 212 °C; kinematic viscosity v = 46.58 mm^2/s at a temperature of 40 °C; acid number AN = 0.025 mg of KOH per 1g of OMTO; the content of mechanical impurities X_m = 0.0032 % mass; water content W – absence (W < 0.03 % mass); “Ionol” additive content S_i = 0.73 % mass;

c) mechanical impurities in OMTO are not metals, fibers or microorganisms and are similar to solid carbon or metal oxides; determination of the content of mechanical impurities in OMTO according to the requirements [6] with the use of a microscope allows to determine the type of mechanical impurities. This indicates the absence of deterioration in the physicochemical and thermophysical properties of the OMTO in the event of a defect associated with damage to the bearing assembly of the electric motor of the water pump unit of the cooling tower of the Rovno NPP. The concentrations of various gases in the OMTO may have the following values (ppm): H_2 – 100, CH_4 –56, C_2H_6 – 500, C_2H_4 – 80, C_2H_2 – 340, C_3H_8 – 30, C_3H_6 – 5600, CO – 260, CO_2 – 280 [27]. The presence of dissolved gases H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, C_3H_8, C_3H_6 in OMTO characterizes the presence of defects of a thermal nature [23, 33].

2. When studying the nature of the temperature effect on the solubility of H_2 in OMTO, it was established that the solubility indicators X_i for H_2 depending on the temperature t in the interval 15...80 °C have the following values: 4.7 % volume – for 15 °C; 5.2 % volume – for 20 °C; 6.0 % volume – for 30 °C; 6.5 % volume – for 40 °C; 7.4 % volume – for 50 °C; 8.0 % volume – for 60 °C; 8.3 % volume – for 65 °C; 8.8 % volume – for 70 °C; 9.3 % volume – for 80 °C.

It follows from the obtained data that the decrease in the solubility of X_i for H_2 in OMTO with a decrease in temperature is similar to the well-known nature of the solubility of H_2, CO, O_2 and N_2 gases in mineral transformer oils [10]. The dependence of X_i (% volume) on temperature t can be expressed by the equation:

$$\ln X_i = 6.36 - 919.8/(t + 273).$$

The obtained results indicate that during the generation of H_2 in the OMTO volume during thermal defects in the bearing unit, the ability of H_2 to dissolve in the OMTO increases with increasing temperature and also the risk of defects in metals associated with hydrogen wear – the process of destruction of metal elements in friction nodes of the bearing due to the absorption of hydrogen by metals [22].

3. The results of the study of the nature of the effect of temperature on the generation of dissolved gases in OMTO and in the “water in OMTO” mixture are shown in Table 1.

Table 1

Effect of temperature on the generation of dissolved gases in the OMTO and mixture “Water in the OMTO”[*]

OS	t	Concentrations of dissolved gases, C_g, ppm										
		H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	C_3H_8	C_3H_6	C_4H_8	CO	CO_2	H_2S
1; 2	20	0	0.9	0	0.4	0	0	0	0	40	45	0
1	100	210	30	8	100	0	9	9	1500	82	160	8
2		200	35	10	110	0	12	13	1400	85	175	9
1	150	240	45	20	155	0	17	18	2500	93	190	13
2		260	50	22	170	0	22	23	2650	94	210	15
1	180	300	60	35	230	0	30	35	2800	110	220	13
2		290	70	38	240	0	38	40	2700	118	240	15
1	250	350	80	55	300	0	50	55	3300	130	250	22
2		330	85	60	330	0	57	62	3200	150	270	25
1	300	440	95	75	380	0	75	70	3800	180	300	60
2		460	100	80	400	0	83	78	3950	190	320	65
1	350	500	110	90	470	0	110	115	4200	210	330	100
2		520	120	95	490	0	120	125	4300	230	350	95

When investigating the nature of the effect of temperature during 150 hours on the generation of dissolved gases in OMTO and in the “water in OMTO” mixture, it was established that the concentrations of C_g dissolved gases in OMTO increase with increasing temperature (Table 1). The concentration of dissolved C_2H_2 gas does not exceed the limits of its determination (0.5 ppm [28, 29]) in the temperature range of 100...350 °C. The concentration of H_2S in OMTO increases sharply in the temperature range of 300...350 °C: it can be used to identify a thermal defect in OMTO with a defect temperature of 300 °C and higher in the friction zone in the bearing nodes with their lubrication circulating OMTO. Concentrations of dissolved gases C_2H_4, C_3H_8, C_3H_6, C_4H_8 in OMTO increase sharply in the temperature range 150...300 °C: it can be used according to the methods [23, 33] to identify a thermal defect in OMTO with a temperature of the defect in the temperature range of 150...300 °C in the friction zone in bearing nodes with their lubrication circulating OMTO.

4. The results of determining the nature of the effect of acoustic cavitation on the generation of dissolved gases in OMTO and the “water in OMTO” mixture are shown in Table 2.

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[*] OS – object of study; t – temperature, °C; C_g – dissolved gas concentration, ppm; 1 – OMTO; 2 – “water in OMTO” mixture

Table 2

Effect of acoustic cavitation on the generation of dissolved gases in OMTO and the “water in OMTO” mixture*

OS	τ	Concentrations of dissolved gases, C_g, ppm										
		H_2	CH_4	C_2H_6	C_2H_4	C_2H_2	C_3H_8	C_3H_6	C_4H_8	CO	CO_2	H_2S
1; 2	0	0	0.9	0	0.4	0	0	0	0	40	45	0
1	200	1900	900	300	3300	600	550	4300	3800	30	200	30
2		2100	1050	350	3500	650	600	4500	3700	40	230	35
1	600	3500	2000	600	4500	900	750	5400	4700	60	230	55
2		3800	2200	700	4700	1000	850	5300	4500	80	280	50
1	1000	4900	2900	700	9300	1300	1000	6500	5600	920	280	90
2		5300	2700	600	8400	900	600	5500	4800	1100	350	85
1	1500	5800	5100	1300	15500	1500	1600	12000	8900	1040	290	200
2		6500	4900	1100	13500	1150	1100	9600	7050	1500	400	190

When studying the nature of the effect of acoustic cavitation on the generation of dissolved gases in OMTO, it was established that the concentrations of C_g dissolved gases in OMTO increase with the increase in the duration of the action of acoustic cavitation (Table 2). The concentration of dissolved C_2H_2 gas in OMTO and the “water in OMTO” mixture exceeds the limits of its determination according to the requirements [28, 29]. This can be used to determine the occurrence of a cavitation regime in the presence of C_2H_2 in the OMTO and a mixture of “water in the OMTO”, for example, in pumping equipment in systems in which this turbine oil circulates and in which there are vibrations (pumps, shell-and-tube oil coolers, etc.). For dissolved gases in the interval of duration of action of acoustic oscillations $\tau = 0...1500$ s in the “water in OMTO” mixture: concentrations of dissolved gases H_2, CO, CO_2, H_2S increase with increasing values of τ; in the interval $\tau = 1000...1500$ s, concentrations of dissolved gases C_2H_6, C_2H_4, C_2H_2, C_3H_8, C_3H_6, C_4H_8 decrease with increasing values of τ. This may be due, for example, to the total chemical reactions of these generated gases from the MTO with water in the MTO in the process of sonochemical reactions in the volume of the MTO:

$$2CH_4 + 3H_2O = 7H_2 + CO + CO_2;$$

$$C_2H_6 + 3H_2O = 6H_2 + CO + CO_2;$$

$$C_2H_4 + 3H_2O = 5H_2 + CO + CO_2;$$

$$C_2H_2 + 3H_2O = 4H_2 + CO + CO_2;$$

$$C_3H_8 + 5H_2O = 9H_2 + CO + 2CO_2;$$

$$C_3H_6 + 5H_2O = 8H_2 + CO + 2CO_2;$$

$$C_4H_8 + 7H_2O = 11H_2 + CO + 3CO_2.$$

When investigating the nature of the effect of acoustic cavitation on the kinematic viscosity ν of OMTO, it was established that with the duration of the acoustic cavitation for 60 min, the kinematic viscosity decreases from the value of 45.8 mm^2/s to the value of 29.0 mm^2/s at a temperature of 40 °C (a decrease of approximately 37 % relative), which corresponds to the known information, for example, regarding hydraulic mineral oil brand AMG-10 (GOST 6794 “Oil AMG-10. Specifications”). When studying the nature of the effect of acoustic cavitation on the density ρ OMTO, it was found that with the duration of acoustic cavitation for 60 minutes, the density did not change and had a value of $\rho = 895$ g/cm^3 at 20 °C. At the same time, it is known that the effect of acoustic cavitation on mineral electrically insulating oils leads to their degradation, similar to the results of exposure to electric fields with the formation of gases H_2, CH_4, C_2H_6, C_2H_4, C_2H_2 [10]. In this case, the hydrocarbons of the original mineral oil are converted into hydrocarbons with a higher molecular weight (this leads to an increase in the density of the mineral oil), for example, according to the well-known chemical reaction: $2C_nH_{2n+2} \rightarrow C_{2n}H_{4n} + H_2$ [34]. This indicates the need to perform additional studies to establish the nature of the impact of acoustic cavitation on the density of OMTO depending on the time of such impact. Thus, increasing the reliability of the NPP power equipment can be achieved by improving the control of physico-chemical and thermophysical properties of OMTO samples of the “Tp-30” brand of

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[*] OS – object of study; τ – duration of acoustic oscillations action, s; C_g – dissolved gas concentration, ppm; 1 – OMTO; 2 – “water in OMTO” mixture

the oil circulation system of water pumping units of the return water supply of evaporative cooling towers of the NPP with the determination of H_2, CH_4, C_2H_6, C_2H_4, C_2H_2, C_3H_8, C_3H_6, C_4H_8, H_2S, CO, CO_2 gases; antioxidant additive “Ionol”; mechanical impurities using a microscope, which allows you to determine the type of these impurities.

Conclusions

1. When studying the physico-chemical and thermophysical properties of fresh MTO and OMTO (density; flash temperature in an open crucible; kinematic viscosity at t = 40 °C; acid number; content of mechanical impurities; water, “Ionol” additive) it was established that indicators correspond to established standards; mechanical impurities in OMTO are not recognized as metals, fibers or microorganisms and are similar to carbon or metal oxides.

2. For OMTO in the temperature range of 15...80 °C, the dependence of the solubility of H_2 X_i (% volume) on temperature t can be expressed by the equation $\ln X_i = 6.36 - 919.8/(t + 273)$ and the solubility of X_i for H_2 in operational MTO decreases as the temperature decreases.

3. When studying the nature of the influence of temperature in its range of 20...350 °C on the generation of dissolved gases in the MTO and in the “water in the MTO” mixtures pre-saturated with air, it was found that the concentrations C_g of dissolved gases in the MTO increase with increasing temperature. The concentration of the dissolved gas C_2H_2 does not exceed the normalized limit in the temperature range of 100...350 °C. The concentration of H_2S in the OMTO increases sharply in the temperature range of 300...350 °C, this can be used to identify a thermal defect in the OMTO with a defect temperature of 300 °C and higher in the friction zone in the bearing units with their lubrication by the circulating OMTO. The concentrations of dissolved gases C_2H_4, C_3H_8, C_3H_6, C_4H_8 in OMTO sharply increase in the temperature range of 150...300 °C and this can be used to identify a thermal defect in OMTO with a defect temperature in the range of 150...300 °C in the zone of circulating OMTO.

4. When studying the nature of the impact of acoustic cavitation on the OMTO and the mixture “water in the OMTO”, it was found that the concentrations C_g of dissolved gases in the OMTO increase with increasing duration of acoustic cavitation. The concentration of the gas C_2H_2 in the OMTO and the mixture “water in the OMTO” exceeds the normalized limits of its determination. It can be used to determine the occurrence of cavitation in the presence of C_2H_2 in the OMTO and the “water in the OMTO” mixture, for example, in the pumping equipment of cooling systems where this turbine oil circulates and in the presence of vibrations. For dissolved gases in the interval τ = 0…1500 s in the mixture “water in OMTO”: the concentrations of dissolved gases H_2, CO, CO_2, H_2S increase with increasing values of τ; in the range τ = 1000…1500 s concentrations of dissolved gases CH_4, C_2H_6, C_2H_4, C_2H_2, C_3H_8, C_3H_6, C_4H_8 decrease with increasing values of τ. This may be due, for example, to the total chemical reactions of these generated gases from the MTO with water in the process of sonochemical reactions in the volume of the MTO. With the duration of acoustic cavitation for 60 minutes at OMTO: the kinematic viscosity ν decreases from the value of 45.8 mm^2/s to the value of 29.0 mm^2/s at a temperature of 40 °C; the density ρ did not change and had a value of ρ = 0.895 g/cm at a temperature of 20 °C.

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