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Impact of undissolved gas on the performance characteristics of hydraulic fluids and characteristic of hydraulic system

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Impact of undissolved gas on the performance characteristics of hydraulic fluids and characteristic of hydraulic system

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Abstract. Almost in all cases, the hydraulic fluid contains not only the liquid phase of the used oil but also by the gaseous phase, which is often air. Air and oil form a while tanking and pressure drop in particular areas of fluid flow. It can be during dynamic processes due to different rates of gas dissolution and evolution from the fluid. The value of gas compressibility is much bigger than the fluid one, it is necessary to investigate the impact of the gas content of hydraulic fluids on the operation of hydraulic systems. This paper considers analyzing the impact of the gas content of oils on characteristics of hydraulic devices and the properties of hydraulic fluids and the degree of their variation with the amount of undissolved air.

1. Introduction

One of the properties of hydraulic fluids used as energy carriers in hydraulic systems is the solubility gas. It means that gas molecules are in the intermolecular fluid space. Such the gas is dissolved, unlike the entrained gas that has a form of bubbles in a fluid.

The impact of dissolved gas on the operation of hydraulic devices is pervasive in apparatus having significant volumes of the hydraulic fluid with the non-permanent pressure and temperature. Such apparatus are actuators and connecting pipelines in electro-hydraulic mechanisms.

The value of c_1 is the air solubility of the pressure equal to 1 atm. In this case, the air solubility for mineral oils and hydraulic fluid of 1 atm depends on the specific gravity of the oil:

$$c_1 \cdot 10^2 = 45{,}11 - 41{,}64 \cdot \gamma, \tag{1}$$

where γ – the specific gravity of the oil.

This equation above permits to approximately find the air solubility for mineral oils if their specific gravity is foregone. It represents the impact of density that is one of the main parameters of mineral oil on the air solubility. The density increasing, air solubility of mineral oil decreases.

Hydraulic devices sometimes have areas where the hydraulic fluid is tangent to air and is entrained into the hydraulic system, for example, in an intensifier with a jet pipe. Entrained air under pressure begins to dissolve in the hydraulic fluid. That is what increases the content of dissolved air in the fluid. However, if there are no areas of direct contact of the hydraulic fluid and air during the operation of the hydraulic system, the hydraulic fluid contains the dissolved air even before filling the system under ordinary conditions and atmospheric pressure.

The content of undissolved gas adversely affects the reliability of the operational properties of the hydraulic fluids and the parameters of hydraulic equipment. Thereby the performance of the hydraulic system reduces. Figure 1 shows the classification of the impact of the gas factor on the properties of mineral oils and the parameters of hydraulic systems.

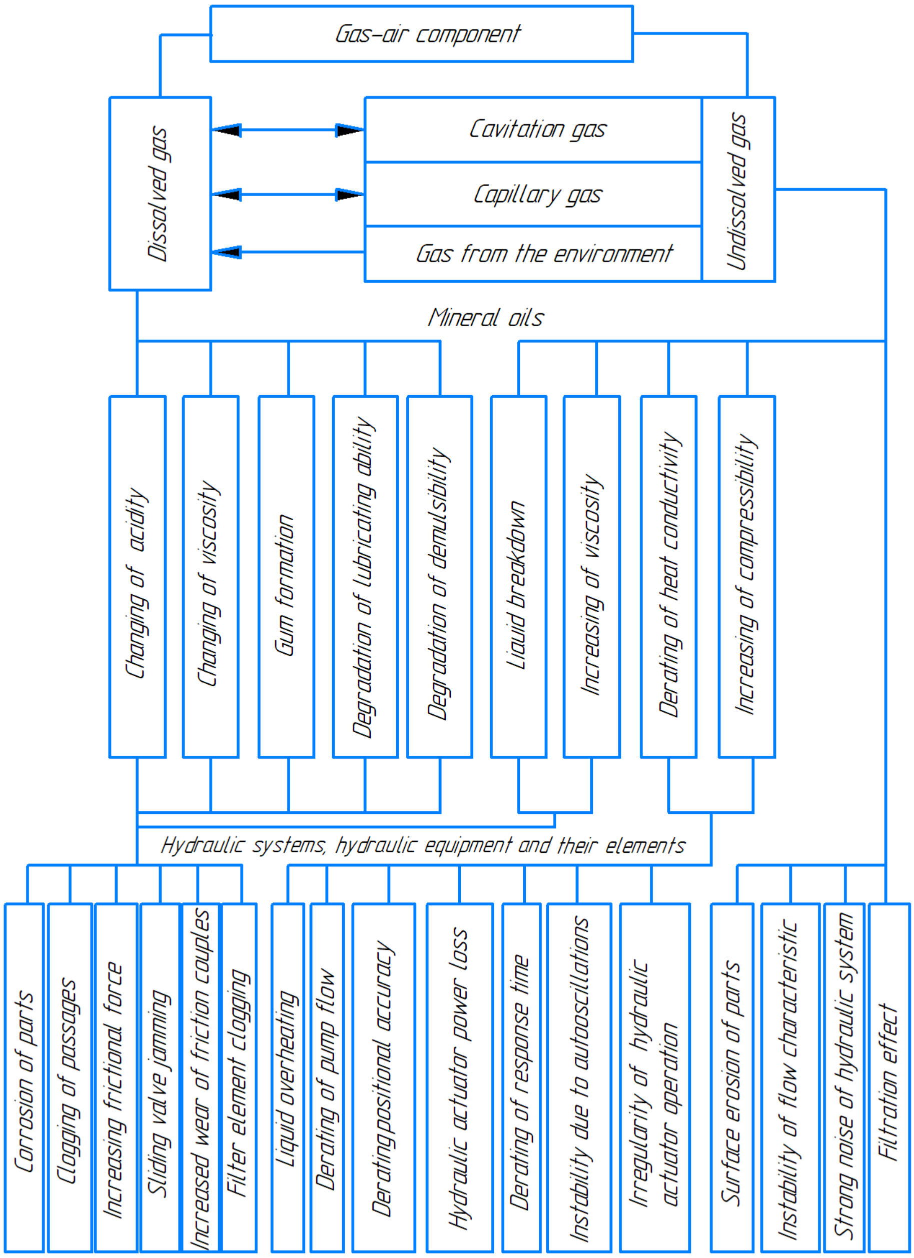

Figure 1. The classification of the impact of the gas factor on the properties of mineral oils and hydraulic system parameters.

2. The impact of the gas factor on the characteristics of hydraulic fluids

Investigative and field researches [1] show that the process of fluid degassing is very slowly. The content of undissolved air in the hydraulic fluid significantly increases the surface used to oxygen diffusion. The result of oxidation is the increase of the oil viscosity [2, 3, 4], buildup acidic products of deterioration, such as hydroxy acids, resins, asphaltenes that decays its anti-corrosive ability. The lubrication performance and demulsibility get worse. Papers [2, 5, 6] tell that the resinous oxidation product precipitates. These cause the increased wear of the friction couple, jamming of the spool-type couple, siltation of throttling trench, and a thrashing of filter elements [7]. The presence of air bubbles causes the dangerous of the probability of a “diesel effect” [2, 8, 9, 10] in the medium under isentropic compression.

The fluid having the p undissolved gas in dispersed form, its viscosity increases. For example, mineral oil containing 10% air has a viscosity of 15% higher than the pure one [11]. In some cases, it impacts on the value of the hydrodynamic load-carrying capacity of the oil film. Air bubbles disrupt oil film that leads to an extension of the space of metal-to-metal contact and increased wear [6]. The presence of a dispersed gas-air factor in the hydraulic fluid and especially the accumulation of it in the form of lumped volumes in the dead ends of the hydraulic systems adversely affect the heat exchange process, so the heat air conduction is much lower than the oil one [6]. The presence of air bubbles in the fluid reduces the bulk modulus of the compressible medium. Thus, one percent of undissolved air decays the bulk modulus of the mixture by 40% [12].

The following equation gives bulk modulus of the mixture

$$B_{mix} = -V_{mix} \frac{\mathrm{d}p}{\mathrm{d}V_{mix}}, \tag{2}$$

where B_{mix} – the bulk elastic modulus of the mixture under unrestricted pressure p; V_{mix} – the volume of the mixture under unrestricted pressure p; $\mathrm{d}p$ – an infinitesimal increment of pressure; $\mathrm{d}V_{mix}$ – an infinitesimal increment of the volume of a mixture.

The maximal change in the bulk mineral oil modulus due to the content of free gas occurs under the pressure of less than 5 MPa [13].

An increase in the compressibility of the medium causes a deterioration in its function of the link transferring pressure energy. It is an undesirable event for hydraulic self-control systems requiring high accuracy and operation speed. Thus, researches [14] of the dependence of the response time and excessive correction on a unit disturbance at the inlet of the hydraulic booster with and without air in cavities show that the presence of undissolved air in the hydraulic fluid increases the excessive correction to 20% and the response time to 30%. The undissolved air can also lead to a decrease in the stability of the hydraulic system, in particular, the follower system.

The formula [12] determines the volume content of gas under atmospheric pressure p_0:

$$\alpha_g = V_{g.0} / V_{mix.0}, \tag{3}$$

where α_g – the volume gas content; $V_{mix.0}$ – the volume of the mixture under atmospheric pressure p_0, $V_{g.0}$ – the volume of gas under atmospheric pressure p_0;

$$V_{mix.0} = V_{l.0} + V_{g.0} \tag{4}$$

where $V_{l.0}$ – the volume of liquid under atmospheric pressure p_0.

Then the following formula characterizes the ratio of the volume of the liquid component to the volume of the mixture under atmospheric pressure p_0:

$$\frac{V_{l.0}}{V_{mix.0}} = 1 - \alpha_g. \tag{5}$$

3. The impact of gas content on the operation of hydraulic devices

The presence of an undissolved gas-air component in the hydraulic fluid reduces the performance of hydraulic equipment. For example, the compressing time of the hydraulic press arrangement increases sharply when the elastic modulus of the fluid decreases due to an enhance in gas content [15]. The compressibility of the fluid filling the work volume of the hydraulic actuator requires additional energy consumption for its compression. The working volume of the hydraulic motor and the speed of its operation increasing, the power loss increases. For example, while using a hydraulic fluid with a bulk modulus of 1406 MPa in a drive with a response frequency of 100 Hz and a hydraulic cylinder with a volume of 164 cm^3, the power loss will be about 5 kW for every 5.8 cm^2 of piston area under a system pressure of 21 MPa. The hydraulic system operating under pressure equal to 21 MPa with a flow rate of 15 lpm and a power of 5 kW cannot move the load with a frequency of 100 Hz because it needs to take all power for compressing of the fluid [16].

The undissolved gas in the hydraulic fluid enhances the high-frequency pressure vibration in the duct of the hydraulic equipment and pipelines. That leads to an increase in the noise of the hydraulic system. According to the data given in [17–7–18], the presence of 2–3% of undissolved air can increase the noise by up to 10 dBA. The tests conducting with a pumping unit based on a pump with a valve distributor show a decrease in the noise level by 3 dBA after fluid degassing.

4. Gas evolution from the hydraulic fluid

It is experimentally proved [19] that the presence of a dissolved gas component does not change the elastic properties of liquids. However, the dissolved phase may cause such an unpleasant phenomenon as cavitation.

The evolution of a gas-air component in t increasing space of the pumps (gas cavitation) leads to the underfilling of the operating chambers and a decrease in displacement to its starvation [20, 21]. It is estimated that when the content of the undissolved gas factor is 5%, the delivery coefficient under a pressure of 20 MPa decreases by about 10% [16]. The gas amount released from the hydraulic fluid depends on three things: the fluid type, the rate among the fluid flow pressure and the bubble point pressure of the dissolved gas, and temperature. So intensive air release in the AMG-10 oil (aviation hydraulic fluid) leading to pump starvation starts at a temperature of 18 °C when the pressure in the stream decreases to a value equal to half the pressure of saturation of the liquid with air. The temperature of the fluid increased, the critical pressure in the flow increases. It is already 75% of the saturation pressure at 60 °C [20].

The phenomena of gas cavitation in the throttling elements change the flow structure and pressure distribution in the wetted part. It can significantly affect the capacity of the throttle gap and the forces acting on the shut-off-and-regulating element of the hydraulic unit. The phenomena lead to instability of the flow characteristics and the blockage effect of the throttling element [22-7-23]. The blockage effect is that the fluid flow through the throttling element stops to increase together with enhancing pressure drop under constant pressure at the inlet of the throttling element. The minimum value of the pressure drop is a critical one. It is because the fluid flow velocity cannot exceed the propagation velocity of disturbances in it (local sound velocity). The propagation velocity can be lower than the sound one in the air for certain combinations of the minimum pressure in the throttling zone and the volume content of undissolved gas [24, 25].

It is found that the process of gas evolution from the fluid (“capillary” gas) can accompany the flow of hydraulics fluids through capillary channels under certain conditions. This process causes passages to plug. This phenomenon called the filtration effect can account for a decrease in the efficiency of filter made of foam materials [26].

5. Conclusions

Therefore, one of the significant factors, which negatively affect the performance of the hydraulic system elements, its lifetime, and durability, is the presence of a gas-air factor in the hydraulic fluid in the dissolved and, especially, undissolved phase.

References

[1] Gallant H 1962 Untersuchungen von kavitations blasen *Ostereichische Ingenieur-Zeitschrift* **5(3)** 74-83
[2] Backe W 1976 Influence of dispersed air on the pressure medium *Conference on Contamination in Fluid Power Systems* 77-84
[3] Cibula G 1966 Die oxydation bei schmierolen *Mineraloltechnik* **11** 8-9
[4] Vorberg K 1969 Druckflussigkeiten in hydraulikanlagen *Maschinenmarkt* **75(40)** 834-8

[5] Thoenes H W 1976 Zum einflug von luft und wasser auf die leitungsfahigkeit von druckubertragungsmedium und von hydraulikanlagen *Industrie Anzeiger* **98(51)** 888-91
[6] Kazanskij V N 1974 *Steam Turbine Lubrication Systems* (Moscow: Energy)
[7] Avrunin G A 1982 *Improving the reliability and durability of hydraulic equipment and mineral oils when using hydrodynamic dispersants in hydraulic systems* (Moscow: Research institute Mash)
[8] Lohrentz H J 1968 Die entwicklung extrem holier temperaturen in hydraulik systemen und die einflusse dieser temperaturen auf die bauteile und ihre funktion *Mineraloltechnik* **13** 14
[9] Lipphardt P 1976 Kompression von dispergieiter luft in hydrauliksystemen und deren auswirkungen auf das druckubertragungsmedium *Industrie Anzeiger* **98(51)** 883-7
[10] Beyer R 1981 Druckflussigkeiten *Q+P* **25(21)** 37-9
[11] Bashta T M 1971 *Engineering hydraulics* (Moscow: Machine building)
[12] Popov D N 1977 *Dynamics and Regulation of Hydraulic and Pneumatic Systems* (Moscow: Machine building)
[13] Hohlov V A, Prokof'ev V N and Borisova N A 1971 *Electro-Hydraulic Tracking Systems* (Moscow: Machine building)
[14] Kuznecov V N and Golovko Y S 1970 The effect of undissolved air on the transient hydraulic amplifier *Technology and organization of production* **4** 74-5
[15] Belopuhov A K 1971 *Injection Molding. Prepress Problems* (Moscow: Machine building)
[16] Magorien V J 1969 What is bulk modulus and when is it important? *H+P* 98-100
[17] Maas J 1969 Neue wege in der entwicklung hydrostatischer antriebe zu wirksamer larmbekampfung und hohenen wirkungsgrad dur verminderung der hysteresisverluste *0+P* vol **13(11)** 531
[18] Turovskij Z G 1973 *Cavitation Research in Piston Pumps* (Kiev: Book)
[19] Prokof'ev V N 1968 An experimental study of the elastic properties of two-phase working fluids of volumetric hydraulic actuators *Machine building* **2** 87-93
[20] Glazkov M M 1987 *Cavitation in aircraft liquid systems* (Kiev: Book)
[21] Bashkirov V S, Dudkov Y N and Fedin V I 1977 Methods of experimental study of gas generation during unsteady fluid motion in the lines of volumetric hydraulic drives *Hydraulic Drive and Control Systems* 137-42
[22] Abarinova I A, Efimceva N F and Piskunov Y A 1980 Features of the throttling elements of hydraulic systems on a two-phase flow of a working fluid *198th All-Union Conf. Scientific and Tech. Progress in Mech. Engineering and Instrument Engineering* 55-7
[23] Backe W and Benning P 1962 Uber kavitation - serscheinungen in querschnittsverengungen von olhydraulischen systemen *Industrie Anzeiger* **63** 29-36
[24] Martin K S and Padmanabhan M 1979 Pressure pulse propagation in a two-component slug flow *Theoretical Foundations of Engineering Calculations* **1** 16-71
[25] Popov D N 1982 *Non-Stationary Hydromechanical Processes* (Moscow: Machine building)
[26] Timirkeev R G and Sapozhnikov V M 1986 *Industrial Cleanliness and Fine Filtration of Aircraft Operating Fluids* (Moscow: Machine building)