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The concept of microfiltration of hydraulic oil in rail vehicles

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The article presents the issue of microfiltration of hydraulic oil from metallic impurities and water that deteriorate the properties of the oil. Tests carried out on oils have shown that periodic oil replacement in machines or vehicles in accordance with their maintenance documentation ensures that the system is emptied of 95% of impurities from the old oil before pouring the new one. The remaining part, i.e. 5% of impurities, together with the oil remaining on the walls of the pipes or inside other hydraulic devices, will mix with the new oil, reducing its cleanliness class. Periodic replacement of hydraulic oil will not allow for complete cleaning of the system. In extreme cases, poor oil condition may cause disruptions in the operation of the machine with the hydraulic system or its downtime for oil replacement or repair. Filtering the oil in the system while the machine is running will clean the oil from impurities and water, extend the oil's service life, without disabling the hydraulic system. The article includes, among others: the justification for the use of microfiltration of hydraulic oil with portable filtering devices in order to extend the service life of the oil until the next replacement is presented. The main purpose of the article is to present the methodology for testing hydraulic oil in accordance with the requirements of ISO, NAS and SAE in order to assign the oil to a given cleanliness class. Additionally, the results of testing the oil cleanliness class in various periods of operation of the machine with the hydraulic installation on a portable measuring device were presented.

1. Introduction

The technique of filtering hydraulic oil was already known abroad in the 1970s, when there was a conflict in the Middle East. At that time, American troops reported problems with the lubrication of hydraulic systems in military vehicles due to the desert climate. The use of filtration on the civilian market was already widespread in the 1980s in the United States and in Europe in the 1990s. It has only been known in Poland for about 10 years, where periodic replacement of the entire oil is the main practice. It should be emphasized, however, that in this way the oil is replaced only from the tank, and a large part of the contamination remains on the walls inside the hydraulic system [3, 4]. Gradually, as part of various conferences and fairs, some companies, such as Kleenoil, as part of the Preston Group's activities dealing with broadly understood industrial hydraulics, started separate activities in the field of building external stationary systems for filtering hydraulic oil from impurities and the presence of water in the hydraulic system. Figure 1 shows an example view of the operation of a construction machine in conditions of strong sand and dust at the railway and tram tracks while loading coal and working in the area of a road intersection [25].

Fig. 1. View of the working conditions of construction machines in the vicinity of the railway and tram tracks [18, 22]

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This significantly extended the service life of the hydraulic oil and reduced the wear of parts of the hydraulic system machines, in particular in the hydraulic pump - hydraulic distributor system. In construction machines, this is an important issue due to the variability of working conditions and load. Both periodic hydraulic oil changes will not allow for complete cleaning of the system and will result in machine downtime, while stationary oil filtering in the system will allow the oil to be cleaned of impurities and water, which will extend the oil's service life [2, 7].

The aim of the article is to justify the use of microfiltration of hydraulic oil with portable filtering devices in order to extend the service life of the oil until the next replacement in both rail and road vehicles operating in an environment of heavy sand and dust contamination. An additional goal of the article is to present the methodology for testing hydraulic oil in accordance with the requirements of ISO, NAS and SAE on the example of a fatigue testing station for trolley frames operating in an industrial hall [5].

2. Overview of rail vehicles with hydraulic installations

Hydrostatic drives, unlike hydrokinetic drives, are currently most often used in rail vehicles. Figure 2 shows a hydrostatic hydraulic diagram of the wheel set drive system from hydraulic pumps (4) driven by the combustion engine to hydraulic motors (9) attached to the wheel sets via gears.

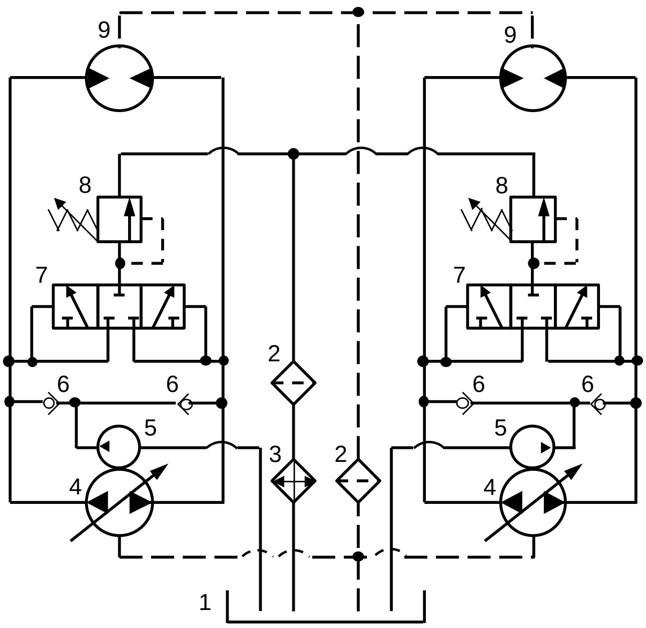

Fig. 2. Schematic diagram of the hydrostatic drive system of a light rail vehicle: 1 – oil tank, 2 –oil filter, 3 – oil cooler, 4 – high pressure pump with variable displacement, 5 – supplementary pump, 6 – check valve, 7 – hydraulic distributor, 8 – safety valve, 9 – hydraulic motor

In Figure 2, the continuous line shows the direction of oil flow supplying the system, while the dashed line shows the oil return to the hydraulic tank. These are light auxiliary, work vehicles for maintaining infrastructure and traction networks, such as motor bogies (draisines), network vehicles, rail and road vehicles, as well as light two-axle shunting locomotives. Hydrostatic drive systems were used, among others, in work vehicles manufactured by the Rail Vehicles Plant in Stargard [13, 14] and in the Iveco Eurocargo 140 rail-road vehicle for cleaning tram infrastructure manufactured by the Rail Vehicles Institute in Poznań [17]. The hydrostatic drive consists of a hydraulic pump mounted on the shaft of the internal combustion engine and hydraulic motors mounted on the axial gears of wheel sets. These assemblies are connected by a hydraulic installation in the form of a hydraulic distributor, hydraulic lines and filters, creating a closed circuit. The medium transmitting the driving torque is hydraulic oil. The system also includes the oil tank, oil cooler and valve system. A hydraulic pump driven by an internal combustion engine generates hydraulic oil pressure, which is converted into torque in hydraulic motors [6, 20]. Solutions for hydrostatic and mechanical systems in rail vehicles have already been described in [16].

The first vehicle with a hydrostatic drive system is the WM-15H motorized trolley, as shown in Fig. 3.

Fig. 3. General view of the WM-15 motor trolley [28]

It is a vehicle manufactured by the former Rolling Stock Repair Plant in Stargard. The motorized stroller has two body versions. The first WM-15A basic version with a cargo box with a capacity of 8 m^3 and a load capacity of 15 tons with a hydraulic crane with a lifting capacity of up to 1.5 tons and WM-15P version for the network emergency service equipped with a basket boom placed on the platform with a lifting height of 11 meters and a lifting capacity of 200 kg. The trolley's drive system consists of a 240 kW Deutz internal combustion engine driven by a flexible clutch, a set of hydraulic pumps with variable displacement and oil pumping direction, which powers two hydrostatic engines connected to axial gears and drive attachments [21].

Another example of a vehicle with a hydrostatic drive is the PS-00.M/B network train (Fig. 4).

Fig. 4. General view of the PS-00.M/B type network train [19]

It is a two-unit railway vehicle intended for repairs and maintenance of traction network equipment. The vehicle allows work to be carried out on network support structures located within a gauge of up to 7.1 m from the track axis from a moving platform [12]. The following devices are installed on the vehicle: fixed platforms, movable platform, hydraulic crane, two-arm net position corrector, control and measurement pantograph, net displacement rollers, hydraulic winches [15]. The train's drive system consists of a Deutz TCD 2015 V 064V diesel engine, a piston-axial hydrostatic pump with variable oil flow and direction, and two hydrostatic engines with variable oil absorption, mounted to two-stage axial gears. The drive system is controlled by the controller as in the WM-15H.00 motorized trolley [12].

Another rail vehicle with a hydrostatic system for driving wheel sets is the network maintenance and lighting vehicle (PUSiO), as shown in Fig. 5.

Fig. 5. View of the PUSiO vehicle [24]

It is a vehicle intended for repairs and maintenance of the traction network and other devices suspended on traction structures, as well as for the ongoing maintenance of the technical condition of platform roofs, lighting, bridges and viaducts. The vehicle is equipped with devices such as a fixed and movable platform, a two-arm net position corrector, a control and measurement current collector, net displacement rollers, and hydraulic winches [16]. The drive system consists of a Deutz combustion engine type TCD 2013 with a power of 181 kW, an axial piston hydrostatic pump with variable displacement and variable discharge direction, two high-pressure hydrostatic piston engines with variable displacement and two-stage axial gears [20].

Hydrostatic systems are also found in rail-road vehicles maintaining railway and tram infrastructure. The drive system of these vehicles consists of a hydrostatic pump with variable capacity and variable discharge direction driven by the 134 kW Iveco Eurocargo internal combustion engine, as shown in Fig. 6. The hydrostatic pump drives axial hydrostatic engines that operate in series [8, 14].

Hydrostatic motors transmit power to the rollers through a special disc. The operating speeds of auxiliary vehicles are low, not exceeding 80 km/h [13].

Fig. 6. Vehicle: a) rail-road vehicle for cleaning tram infrastructure [23], b) Technical Rescue rail-road Renault UniRoller-S [26]

3. Filtration and microfiltration of hydraulic oil

Hydraulic oil filtration is a method of separating solid substances from liquids by mechanically retaining solid substances on filters using appropriate devices. Filtration is the most commonly used method of separating solids from liquids. Microfiltration, on the other hand, is a filtration method using filters from 1 to 4 μm [1].

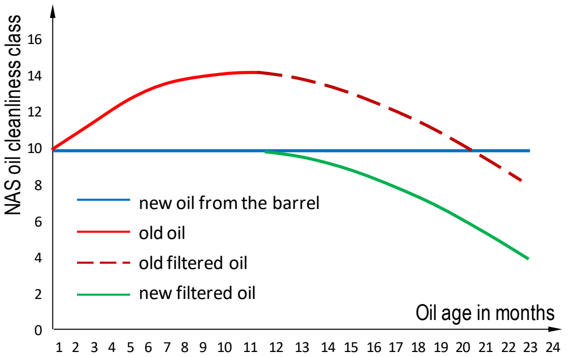

Fig. 7. Dependence of the hydraulic oil cleanliness class according to NAS on the age of the oil [11]

Microfiltration takes place at low pressure (maximum 6 bar). Holes ranging in size from 1 to 4 μm are small enough to stop colloids, suspensions and bacteria contained in the liquid [10]. It should be emphasized that microfiltration allows to reduce the oil purity class; Fig. 7 shows the relationship between the oil purity class and the age of the oil [11]. Additionally, Table 1 presents a list of hydraulic cleanliness classes for the requirements set for various hydraulic devices [27].

Table 1. Hydraulic oil cleanliness classes according to ISO and NAS [10]

Oil cleanliness class		**Required oil cleanliness class**			
ISO 4406	NAS	Pumps and motors	Valves	Bearings	Drives
23/21/18	**12**	Oil very contaminated. Absolute oil change or microfiltration with cleaning of the hydraulic system			
22/20/17	**11**				
21/19/16	**10**				
20/18/15	**9**	reverse	gears		
19/17/14	**8**	vane, piston	proportional, mushroom-shaped	sliding	cylinders
18/16/13	**7**				
17/15/12	**6**			roller	hydrostatic
16/14/11	**5**	Highest precision servomechanisms used in aviation			
15/13/10	**4**				

According to Table 1, the three ISO code numbers describe contamination levels for particles > 4 μm, > 6 μm and >14 μm, respectively. Oil cleanliness class 4 and 5 is absolutely required in hydraulic systems used in aviation. The use of oil filtration will allow the extension of the oil change period in a machine in which the oil change was planned every 800–1000 operating hours [11].

4. Reasons for the increase in the cleanliness class of hydraulic oil

The factors that negatively affect the condition of hydraulic oil are its transport and storage (warehousing). During winter, if barrels of oil are stored outdoors or in unheated rooms, the barrels freeze and water condenses on the internal walls. However, in the summer, water evaporates and water condenses again inside the oil barrels. Figure 8a) shows a view of the inside of the barrel after it has been emptied of oil. Corrosion due to water is visible at the bottom.

It should be emphasized that oil in a metal drum with a capacity of 200 liters may have an ISO purity classification of 23/21/18 [11]. This is rarely sufficient for hydraulic systems, so standard practice should be to filter new oil before filling the reservoir of the device or system. The recommended method is to pass the oil through a separate filter unit before starting the machine or device.

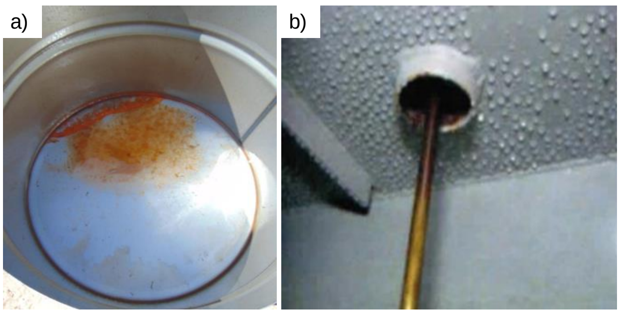

Fig. 8. Reasons for the presence of water in the hydraulic oil: a) view of the internal walls of the hydraulic oil barrel with visible corrosion, b) view of the internal walls of the hydraulic tank with visible water drops [11]

The process of water condensing in the hydraulic system also occurs in the case of a hydraulic tank. Figure 8b shows a view from inside the tank with visible water drops. When changing the oil or adding oil to the hydraulic system, as much as 30% of the old oil remains in circulation. Contaminants remain and are mixed in the oil. Therefore, only part of the oil is replaced with new one. This means that when performing a regular oil change, all deposits and impurities form a suspension and remain in the system. They are then distributed to all parts of the system and the freshly added new oil becomes dirty again.

Depending on external factors, water may appear in various forms in hydraulic oil (Fig. 9) as an emulsion, separated water or dissolved (turbid) water.

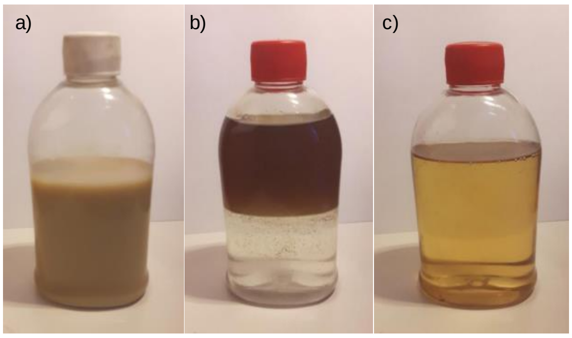

Fig. 9. View a) emulsion, b) separated water, c) dissolved water [11]

In addition to water in hydraulic oil, the second threat to the hydraulic system is metallic contaminants. They are mainly products of wear of interacting elements, such as slider pistons in the hydraulic distributor, pistons in the multi-piston pump housing or piston in the hydraulic cylinder of the actuator.

5. Construction of a hydraulic oil microfiltration system

The device for microfiltration of hydraulic oil from water and metallic impurities is portable and transportable due to its 4 wheels. It consists of an electric motor powered by a 230 V AC mains. The engine is mechanically connected via a clutch to a hydraulic pump, which sucks hydraulic oil from the cleaned system and passes it through a system of cellulose fiber filters and a magnetic filter, as shown in Fig. 10.

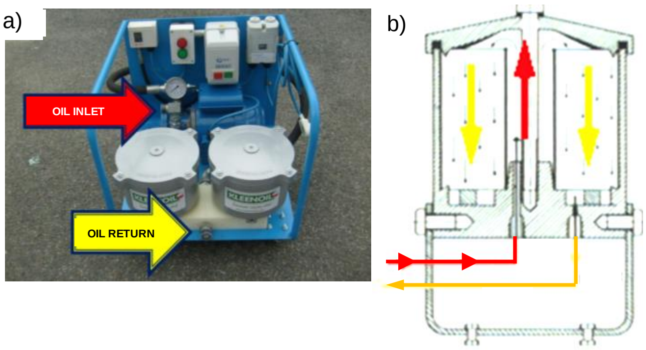

Fig. 10. View of: a) a portable device for filtering hydraulic oil, b) a cross-sectional view of the filter cartridge with the direction of hydraulic oil flow visible [11]

Filtration of hydraulic oil from the presence of water and metallic impurities is performed in a bypass manner, by filtering the oil in the tank during normal operation of the hydraulic system. In this way, the downtime of the device, financial outlays and the amount of oil used due to its more frequent replacement are reduced to a minimum. In a working hydraulic system, the oil becomes dirty again over time and it is advisable to re-filter it.

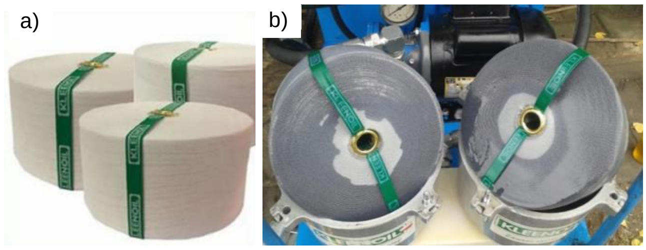

Fig. 11. View of the filter inserts: a) new, b) after microfiltration [29]

Depending on the degree of contamination of the hydraulic oil, the filter cartridges may be replaced at different intervals. Figure 11 shows a view of a new and contaminated Kleenoil filter cartridge.

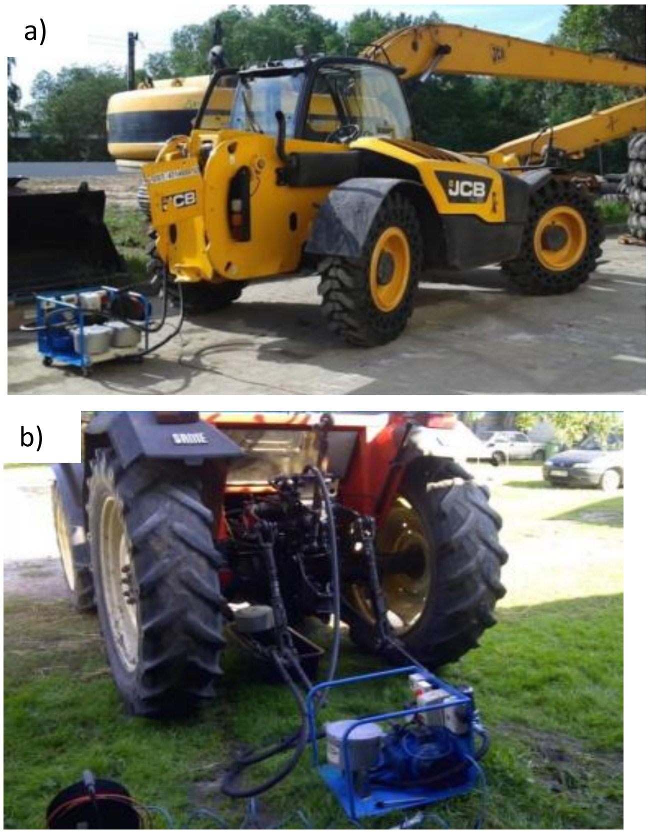

Fig. 12. Examples of applications of a portable hydraulic oil filtering device in: a) construction machinery, b) construction machinery (telescopic loader), b) agricultural tractor [10]

Figure 12 shows various examples of hydraulic oil filtration applications. These include applications in production machines powered by hydraulic devices, as well as construction machines, road machines and other vehicles.

6. Methodology and results of hydraulic oil testing

Hydraulic oil testing is carried out, among others, by: on portable oil condition analyzers such as OP-ComII Portable Oil Lab PPCO 300-1000 by HydroAtos, as shown in Fig. 13.

Fig. 13. View of the OPComII Portable Oil Lab PPCO 300-1000 portable oil condition analyzer from HydroAtos

The basic parameters of the measuring device are presented in Table 2.

Table 2. Technical parameters of the OPComII Portable Oil Lab PPCO 300–1000 device

Name	Value
Working pressure range	2.5–350 bar (35–5000 psi)
Range of working viscosities	from 1 to 300 cSt
Working temperature	–30°C to +80°C
Operating temperature for fluid (oil)	+5°C to +80°C
Operating temperature for fluid (fuel)	–20°C to +70°C
Permissible relative ambient humidity	from 5% RH to 100% RH

After testing in field or laboratory conditions, it is advisable to perform microfiltration of hydraulic oil using the MS2+MM5 Kleenoil device, as shown in Fig. 9a in Chapter 5 of the article. Figure 14 shows a view of the fatigue testing station for a tram bogie with a hydraulic power supply system for hydraulic actuators and an oil microfiltration device. Hydraulic cylinders act on both sides of the torsion beam located in the central part of the bogie frame, which allows the simulation of loads coming from the body of a rail vehicle.

Hydraulic oil type HV46 was used for the tests, which was used to flood the hydraulic system of the test stand. The hydraulic oil cleanliness class was tested in three stages. The first stage concerned the testing of hydraulic oil after several years of use of the test stand. The second stage was related to testing new hydraulic oil before flooding the site. The third and last stage of the research concerned the examination of the oil used in the microfiltration station system. Table 3 shows the results of testing the cleanliness class of hydraulic oil. It should be emphasized that HV46 oil came from a barrel.

Based on the results from the reports, it was found that the oil class increased from 11 to 12 according to the NAS classification, while after cleaning with the MS2 + MM5 device it decreased to class 9.

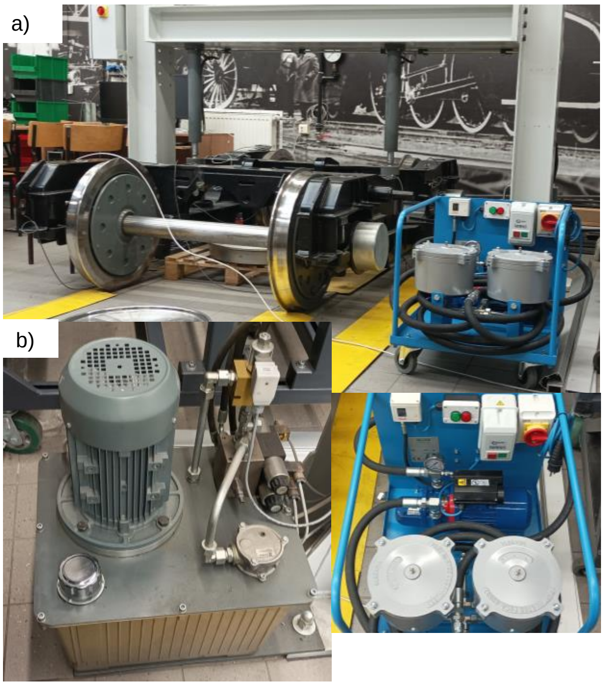

Fig. 14. View of: a) the tram bogie fatigue testing stand, b) the hydraulic power supply system of the test stand

Table 3. Hydraulic oil testing results according to ISO, SAE, NAS and GOST

Oil purity class marking	Oil after several years of use	New oil	New oil after microfiltration
ISO 4 µm	23	20	17
ISO 6 µm	22	18	15
ISO 14 µm	21	15	13
ISO 21 µm	19	14	12
SAE 4 µm	12	10	7
SAE 6 µm	12	10	6
SAE 14 µm	12	9	7
SAE 21 µm	12	10	9
NAS	**12**	**11**	**9**
GOST	17	13	10

According to ISO 4406, the amount of solid particles in oil is defined in three size classes, the American classification SAE AS4059E classifies the cleanliness of oil (mainly in aviation applications), while NAS 1638 specifies the content of water, aluminum, silicon, sodium, chromium and other elements in oil. The GOST classification is used in Russia [9].

7. Conclusions

Microfiltration of hydraulic or transmission oil is becoming more and more common among users of hydraulic systems and among companies performing repairs and inspections of hydraulic installations. Moreover, the ease of ordering the service or purchasing portable systems for bypass filtration of hydraulic oil without downtime of machines or vehicles makes the service more and more common. Due to the increasingly advanced hydraulic systems with servo valves or proportional valves in industrial and precision machines, owners of these machines and users are increasingly ordering periodic hydraulic oil filtering services. In the coming years, we can expect the development of oil microfiltration systems not only as bypass systems for universal use, but also as installations dedicated to specific machines and vehicles.

Based on the literature on filtration and microfiltration and our own research, it was concluded that:

1. Microfiltration allows you to extend the hydraulic oil replacement period by 5 or even 10 times,
2. Hydraulic oil filtration is carried out both before pouring new hydraulic oil into the system, in particular when the installation is filled with oil from a metal barrel, and when it is carried out periodically (in accordance with the technical and operational documentation) on various hydraulic installations.
3. In the case of filtration, it is possible to purify oil from class 12 to class 8, and in the case of microfiltration up to class 3 of oil purity,
4. For hydraulic oils, the purchase of new oil involves the purchase of a mixture of new oil and regenerated oil in a proportion of 60–70%. The oil purchased from the manufacturer is not 100% new crude oil.

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Nomenclature

AC	alternating current
cSt	centystoks
GOST	Gosudarstvennyi Standart
ISO	International Organization for Standardization
NAS	National Aerospace Standard
psi	Pound-Force per Square Inch
RH	Relative Humidity
SAE	Society of Automotive Engineers
WM	Motor vehicle

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