ISSN 1330-3651 (Print), ISSN 1848-6339 (Online) https://doi.org/10.17559/TV-20230524000667
Original scientific paper

Analysis of the Behaviour of the Hydraulic Fluid HM VG 32 and HV 32 at Different Operating Conditions of the Axial-Piston Pump

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Abstract: This paper investigates the behaviour of two types of hydraulic fluids, ISO HM VG 32 and ISO HV VG 32, in hydraulic presses under various operating conditions. The study aims to analyze the influence of these fluids on hydraulic system performance and testing, considering factors such as viscosity, density, and the presence of solid particles. The authors address the problem of hydraulic press systems driven by an axial-piston pump and the changes that occur in different types of fluids of the same kinematic viscosity but of different viscosity grades. Experimental research compares the performance of HM and HV oils before and after filtration, examining parameters such as viscosity and density under different pressures and temperatures. Results indicate that HV oils perform better under high-temperature conditions, while HM oils demonstrate superior performance under normal operating conditions. The study emphasizes the importance of continual monitoring and maintenance to optimize hydraulic system performance and mitigate potential risks associated with fluid contamination.

Keywords: axial-piston pump; filtration; hydraulic press; oil; viscosity

1 INTRODUCTION

Hydraulic systems represent one of the most complex systems that can be found in the industry. When this is said, it means the precision and accuracy required from the operation of all components of the system because otherwise, any deviation from the ideal operation is maintained on the output result. One of the biggest problems with hydraulic systems with large capacities is leaks that can appear in the system. There are permitted leaks that are provided for all components of the system, while there is another type of leak that is considered non-standard, and such an occurrence must be avoided, and if it occurs, the potential causes of the problem must be analyzed.

The practice has so far shown that one of the biggest causes of all failures of the hydraulic system and its components is actually the hydraulic fluid that is in the system itself. The most common oils found in high-pressure systems are hydraulic mineral oils [1].

The operating conditions found in a system can greatly affect the working fluid itself, its performance, and its quality. High-pressure systems and dynamic loads cause, by nature, changes in the structure of the fluid itself, which can cause potential oil contamination, which causes damage within the system components. Pumps are the ones that are the most vulnerable, considering the loads that occur inside the impeller and the pressures that fluids pass through the pump body [2]. Therefore, the basic fluid properties, viscosity, density, and bulk modulus are key parameters when studying hydraulic systems' behavior and the components' operation [3].

Axial-piston pumps have exceptional characteristics. According to the specifications, some create pressures up to 500 bar, which undoubtedly represents a large load on the pump chamber. Pump parameters often behave very non-linearly, so it is sometimes difficult to establish a model that would precisely define a pump failure, but with the help of appropriate diagnostic tools, precise data on the failure can be obtained [4]. In order to get a clear picture of the condition of an axial-piston pump, it must be subjected to different operating modes, that is, different conditions, which were described for pump systems in works [5-8]. Rotary equipment, including axial-piston pumps, requires extremely high performance in hydraulic systems [9].

Considering the required conditions of all components, including pumps for working fluids, the behavior of ISO HM VG 32 and HV 32 fluids is projected at different pressure and temperature parameters, which are a function of changing the kinematic viscosity and density of the oil itself. In order to bring the exploited oil to an optimal condition without replacing it, it is necessary to carry out the process of filtration of the hydraulic fluid and then compare the filtered oil, unfiltered oil, and the prescribed parameters for the given type of oil. Adequate testing of the oil, using viscometers and laser devices for assessing the presence of solid particles and relative humidity in the oil, provides a picture of the current state based on which further behavior of the hydraulic oil in the press system is projected.

2 INFLUENCE OF HYDRAULIC FLUID ON THE OPERATION OF THE HYDRAULIC SYSTEM AND ITS TESTING

Hydraulic fluids and their quality is the most influential factor in the operation of hydraulic components, in the paper [10]: Singh claims that as much as 70% of the causes of all failures in the hydraulic system is oil. Contamination of the hydraulic fluid can lead to three stages of failure in the hydraulic system:

- Phase I: System failure due to degradation: the cause of this phase is wear and tear of component bodies, abrasion, corrosion, or erosion.
- Phase II: Severe catastrophic failures: the fluid in which there are large solid particles leads to the jamming of the pumps and the stoppage of the fluid flow,
- Phase III: Periodic failures: minor failures on the distribution valves are the most frequent, jamming the spool.

All phases significantly reduce the system's performance, so it is necessary to control the quality of the hydraulic fluid in the system periodically, in a precisely determined period of time. The purity of the working fluid is certainly one of the basic requirements that systems need to fulfill in order for their operation to be considered reliable [11]. Hydraulic fluid testing, whether by laser method or some other optical method, belongs to the group of maintenance and testing of machines and equipment by non-destructive methods, which is shown in Fig. 1.

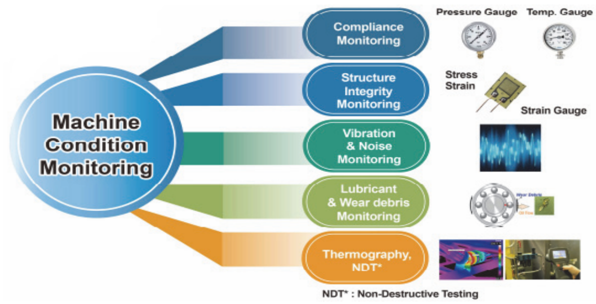

Figure 1 Condition monitoring of technical systems [12, 13]

Testing of the hydraulic fluid can be performed in offline mode and online mode, depending on the possibility of implementing the diagnostic tool [14]. The purification of hydraulic oil is a crucial aspect of maintaining the efficiency and longevity of hydraulic systems. Various methods of oil filtration have been developed to remove contaminants and extend the service life of hydraulic components. These methods encompass mechanical, chemical, and electrostatic filtration techniques, each offering distinct advantages in terms of particle removal efficiency and adaptability to different operational environments. For the purposes of this research, the HYDAC OLF-M filtration device with a filtration fineness of 2 microns was utilized. This particular device offers precise filtration capabilities suitable for removing a wide range of contaminants from hydraulic oil, thereby enhancing the reliability and performance of hydraulic systems in various industrial applications.

In the initial phase, the oil is tested for the presence of solid particles within the oil structure itself (4 µm, 14 µm, 16 µm). Based on the obtained values, it is determined whether the oil belongs to the required standard class, that is, whether the number of solid particles exceeds the permitted established values. If the oil is dirty, according to the number of solid particles present in the oil, a decision is made on further measures, whether the oil can be filtered to a satisfactory level or whether it must be replaced with a new one. In this phase, the presence of moisture inside the hydraulic oil is also examined. The second phase of the test is the test of the kinematic viscosity of the hydraulic fluid before and after the hydraulic oil filtration process. Each of the components in the system has a minimum and maximum permissible limit of the required kinematic viscosity. Therefore, the viscosity must have precisely defined limits taking into account the system's requirements, especially due to uniform flow, which directly affects the system's efficiency [15].

The presence of solid particles leads to the biggest problems within hydraulic systems because they can cause physical damage to the components and thus significantly reduce their efficiency [16, 17]. When it comes to kinematic viscosity, it plays a big role in the behaviour of system components because it can cause unwanted leaks, and the factor that most affects the change in kinematic viscosity is temperature, which can further cause a change in pressure in the system and thus directly affect operating reliability [18]. In their paper, Novaković et al. described the influence of the quality of the working fluid on the behaviour of the hydraulic system of a press with a gear pump [19]. One of the biggest causes of reduced performance of hydraulic fluids is the excessive presence of water in the oil [20].

When analyzing the density of the working fluid and its behaviour under different conditions, it is taken into account that it is an adiabatic process. Accordingly, the formula for determining the kinematic viscosity is defined as [21-23]:

$$\rho(t) = \rho(t)_i \cdot \left(\frac{\Delta p}{K_s}\right) \tag{1}$$

where $\rho(t)$ represents the oil density, $\rho(t)_i$ represents the oil density on specific temperature, Δp represents the pressure difference, and K_s represents the isentropic bulk modulus, while kinematic viscosity can be defined according to the equation:

$$v = v_0 \cdot (1 + k \cdot p) \tag{2}$$

where v represents the kinematic viscosity, v_0 represents the kinematic viscosity at atmospheric pressure, k represents the coefficient of change in kinematic viscosity due to pressure change, and p represents pressure.

3 CHARACTERISTICS OF HYDRAULIC OIL HM VG 32 AND HV VG 32

In addition to standard hydraulic mineral oils with a viscosity of 46 mm^2/s, one of the most commonly used oils in hydraulic press systems are oils with a kinematic viscosity of 32 mm^2/s, determined under atmospheric pressure conditions of 1 bar. The HM oil-type formulation was developed with the development of vane pumps but was later quickly transferred to other components found in high-pressure systems. Oils containing a base of zinc and phosphorus have become increasingly applicable in hydraulics. Given that viscosity is the basic characteristic of system lubrication, in certain cases of application, it becomes necessary to stabilize it as a function of temperature changes, so viscosity improvers and polymer materials of different formulations are added to the HM formulation. This procedure leads to the formation of HV-type oil. This type of oil has a high viscosity index, ranging between 140 and 200, which is not the case with HM oil, where the viscosity index is approximately 100.

4 EXPERIMENTAL TESTING OF THE BEHAVIOR OF HYDRAULIC FLUIDS ISO HM VG 32 AND ISO HV VG 32

Examination of the hydraulic fluid begins with the diagnosis of the fluid itself, examination of the presence of solid particles, and then viscosity and the presence of moisture in the fluid. Tab. 1 shows the characteristics of the hydraulic fluid measured in conditions where atmospheric pressure is present. The requirements for solid particles, moisture, and viscosity are defined based on the prescribed standards of ISO 4406-05. The alphanumeric codes found in tables, such as "21/21/18" according to ISO

4406-05 standard, denote the quantity of solid particles present in 1 ml of the tested hydraulic oil. The first alphanumeric code signifies the quantity of solid particles with a size of 4 microns, the second in sequence represents particles sized at 6 microns, while the third alphanumeric code signifies particles of 14 microns in size.

Tab. 1 and Tab. 2 show the results of hydraulic oil diagnostics before and after filtration.

Table 1 Analyzed hydraulic oil before the filtration process

Description and sample identification	ISO HM VG 32			
Characteristics	Units	Methods	Results obtained	Oil purity requirements
Oil purity	ISO cod	ISO 4406-05	21/21/18	19/17/14
Relative humidity RH	ISO cod	ISO 4406-05	53%	30 - 80%
Viscosity	mm^2/s	ISO 3104	31,009	32

Table 2 Analyzed hydraulic oil after the filtration process

Description and sample identification	ISO HM VG 32			
Characteristics	Units	Methods	Results obtained	Oil purity requirements
Oil purity	ISO cod	ISO 4406-05	19/18/14	19/17/14
Relative humidity RH	ISO cod	ISO 4406-05	43%	30 - 80%
Viscosity	mm^2/s	ISO 3104	31,559	32

Based on the values obtained by analyzing the oil before and after the filtration process, it is possible to project the behaviour of the parameters of the hydraulic fluid under different operating conditions for the given system and, based on the obtained results, compare the deviations from the recommended, ideal conditions for the given oil.

Fig. 2 shows the kinematic viscosities of hydraulic oil ISO HM VG 32 at an atmospheric pressure of 1 bar.

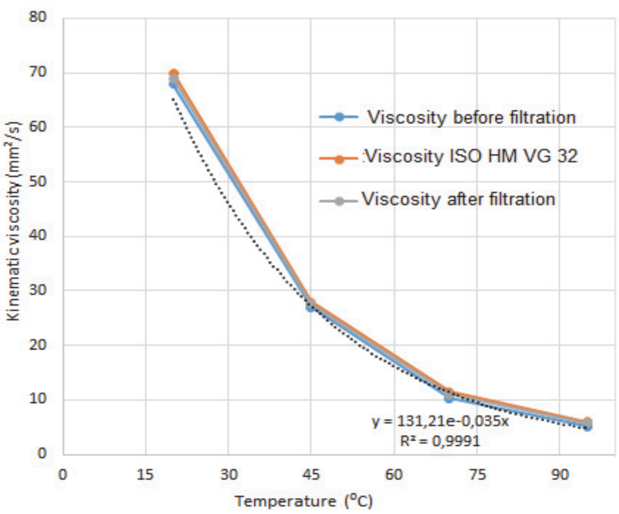

Figure 2 Kinematic viscosity of hydraulic oil ISO HM VG 32 at atmospheric pressure

The hydraulic press in the pressing mode in the first operating mode reaches a pressure of 150 bar, so Fig. 3 shows the behaviour of the oil at an operating pressure of 150 bar.

Tab. 3 shows the results of the tested oil ISO HV VG 32 before the filtration process.

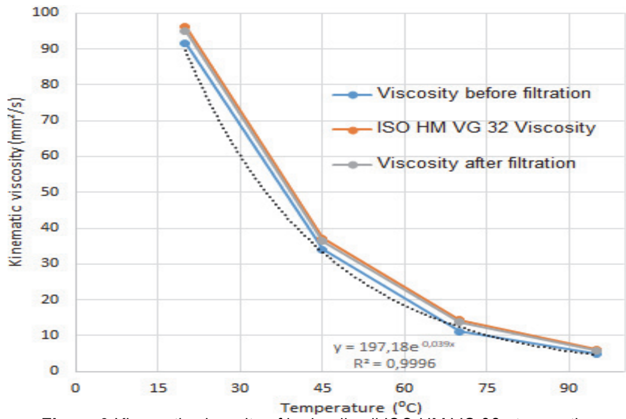

Figure 3 Kinematic viscosity of hydraulic oil ISO HM VG 32 at operating pressure 150 bar

Table 3 Analyzed hydraulic oil HV VG 32 before the filtration process

Description and sample identification	ISO HV VG 32			
Characteristics	Units	Methods	Results obtained	Oil purity requirements
Oil purity	ISO cod	ISO 4406-05	20/21/19	19/17/14
Relative humidity RH	ISO cod	ISO 4406-05	48%	30 - 80%
Viscosity	mm^2/s	ISO 3104	31,102	32

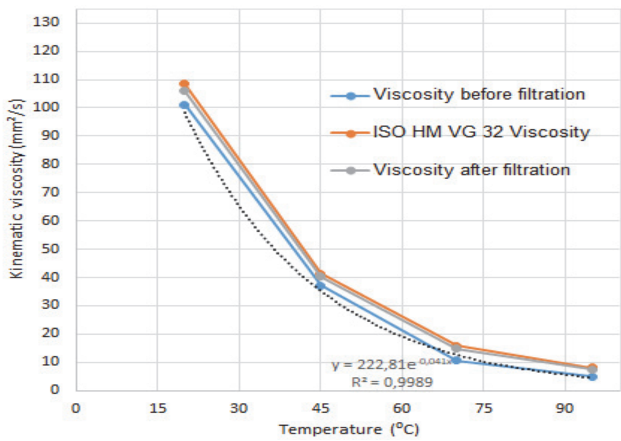

Figure 4 Kinematic viscosity of hydraulic oil ISO HM VG 32 at operating pressure 220 bar

Fig. 4 shows the projection of the kinematic viscosity behaviour at an operating pressure of 220 bar.

Fig. 5 shows the behaviour of kinematic viscosity at a maximum pressure of 350 bar.

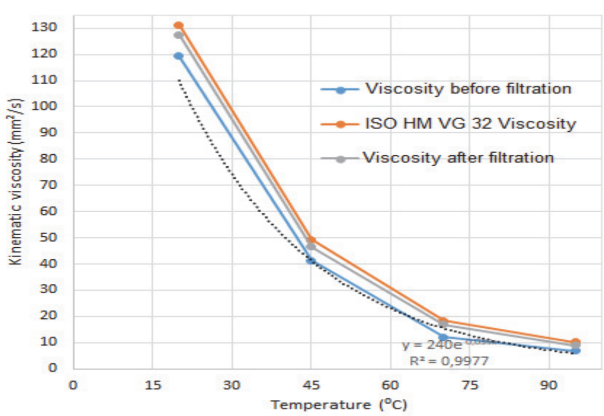

Figure 5 Kinematic viscosity of hydraulic oil ISO HM VG 32 at maximal pressure 350 bar

Tab. 4 shows the results of the test oil ISO HV VG 32 after the filtration process.

Table 4 Analyzed hydraulic oil HV VG 32 after the filtration process

Description and sample identification	ISO HV VG 32			
Characteristics	Units	Methods	Results obtained	Oil purity requirements
Oil purity	ISO cod	ISO 4406-05	19/18/15	19/17/14
Relative humidity RH	ISO cod	ISO 4406-05	41%	30 - 80%
Viscosity	mm^2/s	ISO 3104	31,602	32

Fig. 6 shows the kinematic viscosity of hydraulic oil ISO HV VG 32 at atmospheric pressure.

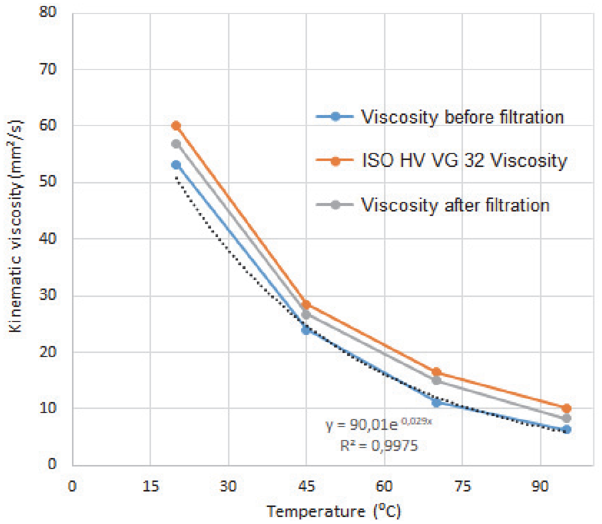

Figure 6 Kinematic viscosity of hydraulic oil ISO HV VG 32 at atmospheric pressure

Fig. 7 shows the projection of viscosity behaviour at the first random pressure of 150 bar.

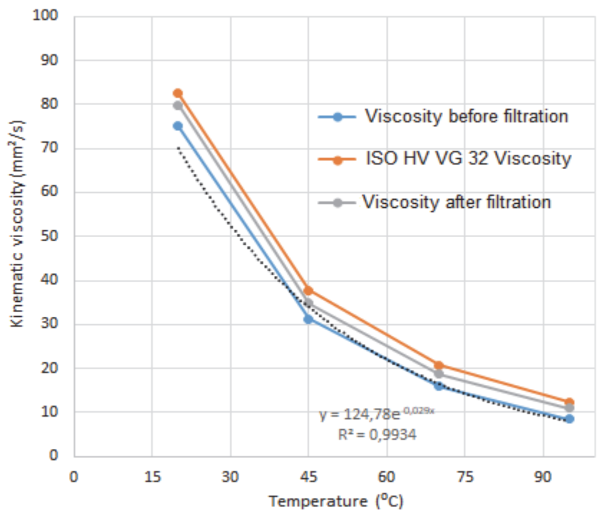

Figure 7 Kinematic viscosity of hydraulic oil ISO HV VG 32 at operating pressure 150 bar

Fig. 8 shows the projection of the hydraulic oil, i.e., its viscosity at the second operating pressure at 220 bar.

Fig. 9 shows the kinematic viscosity at the maximum working pressure of the pump of 350 bar.

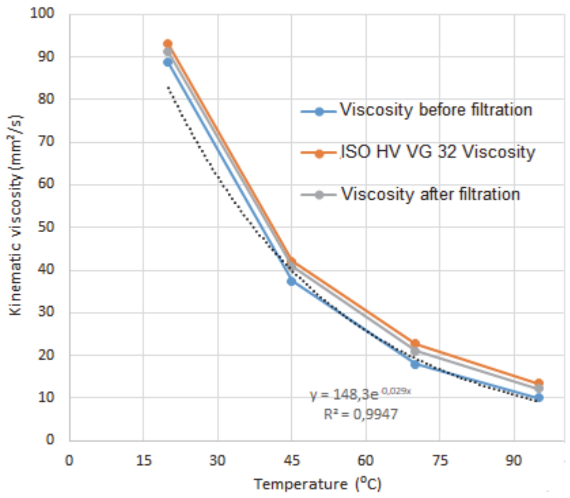

Figure 8 Kinematic viscosity of hydraulic oil ISO HV VG 32 at operating pressure 220 bar

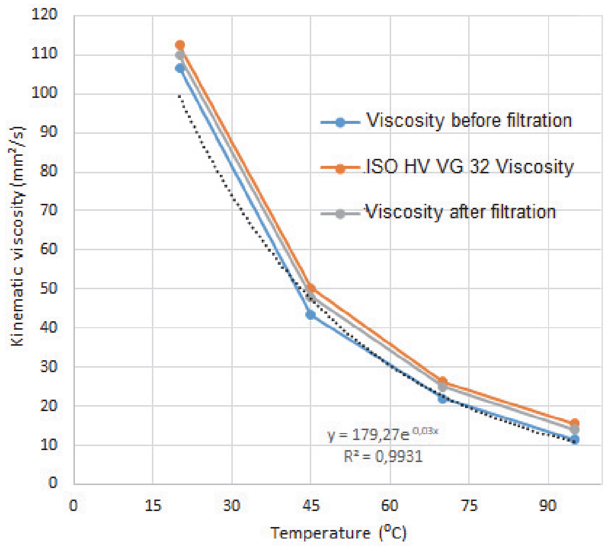

Figure 9 Kinematic viscosity of hydraulic oil ISO HV VG 32 at maximal pressure 350 bar

Fig. 10 shows the density of the working fluid ISO HV VG 32 at all temperature changes at atmospheric pressure.

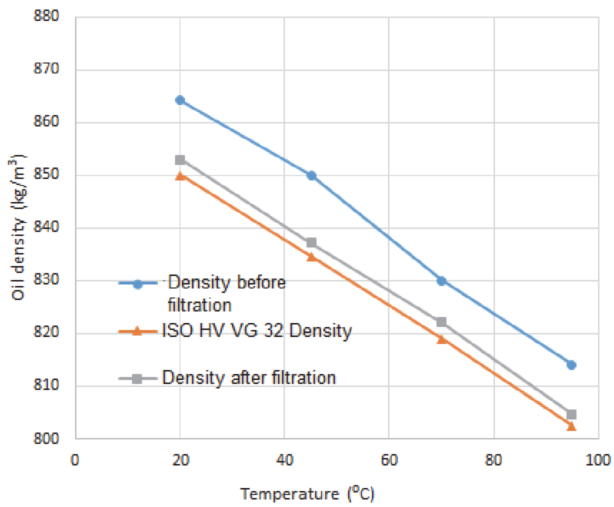

Figure 10 Density of hydraulic oil ISO HV VG 32 at atmospheric pressure

Fig. 11 shows the density at an operating pressure of 150 bar.

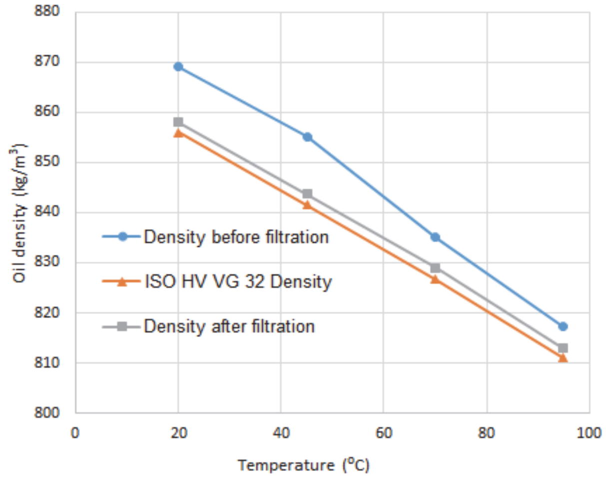

Figure 11 Density of hydraulic oil ISO HV VG 32 at 150 bar

Fig. 12 shows the density at an operating pressure of 220 bar.

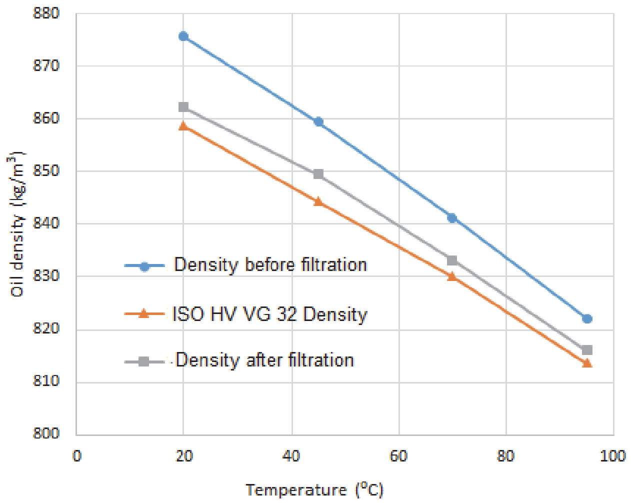

Figure 12 Density of hydraulic oil ISO HV VG 32 at 220 bar

Fig. 13 shows the density at a maximum pressure of 350 bar.

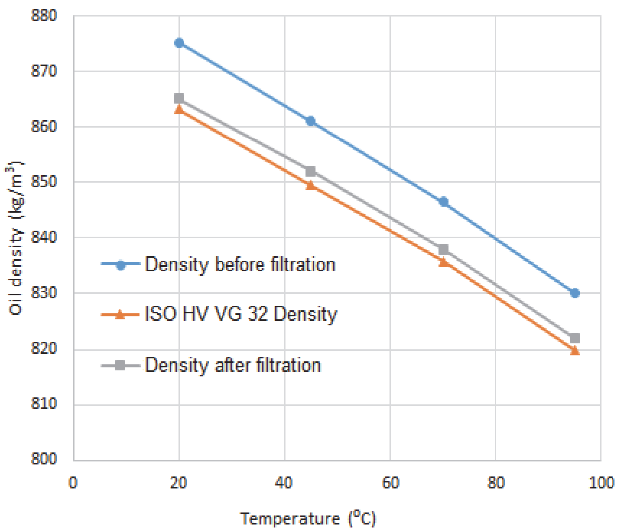

Figure 13 Density of hydraulic oil ISO HV VG 32 at 350 bar

Fig. 14 shows the density projection of the working fluid ISO HM VG 32.

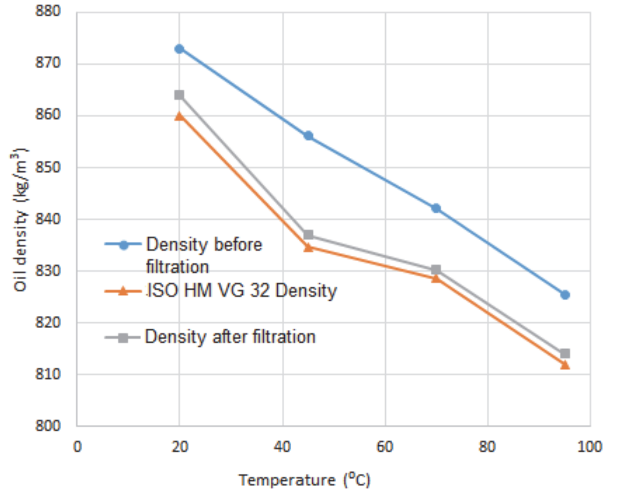

Figure 14 Density of hydraulic oil ISO HM VG 32 at atmospheric pressure

Fig. 15 shows the density of HM VG 32 oil at an operating pressure of 150 bar.

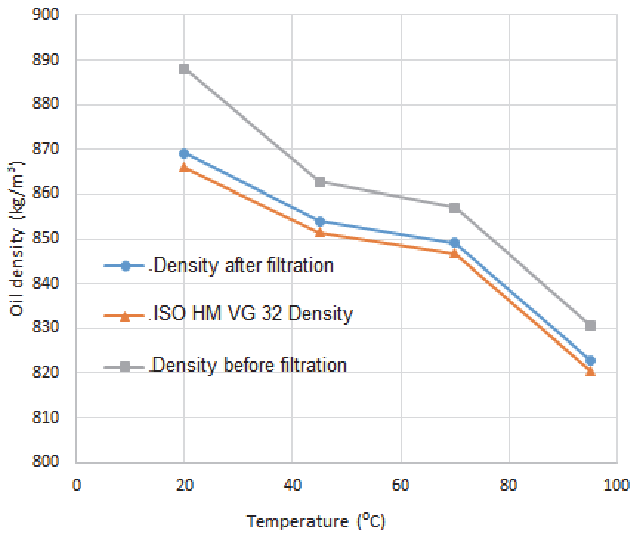

Figure 15 Density of hydraulic oil ISO HM VG 32 at 150 bar

Fig. 16 shows the density of HM VG 32 oil at an operating pressure of 220 bar.

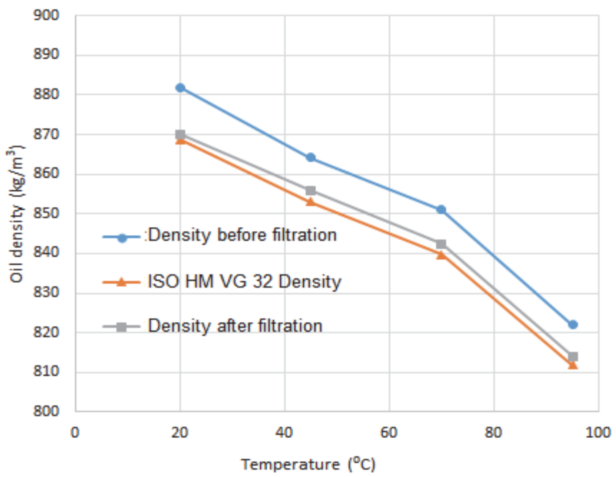

Figure 16 Density of hydraulic oil ISO HM VG 32 at 220 bar

Fig. 17 shows the viscosity at maximum working pressure.

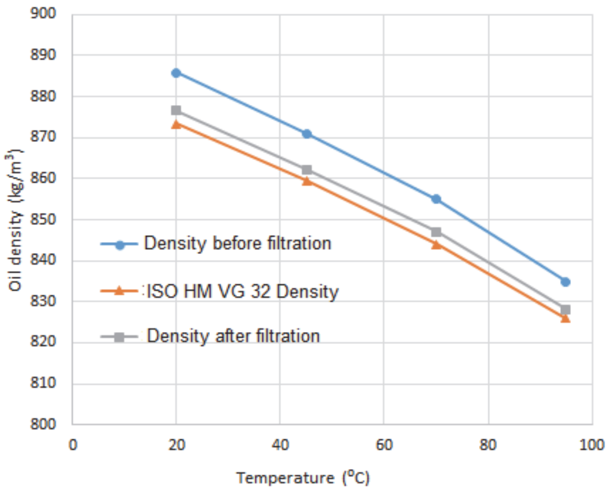

Figure 17 Density of hydraulic oil ISO HM VG 32 at 350bar

5 CONCLUSION

Based on the conducted experimental research for two types of hydraulic fluid used in hydraulic presses with the same parameters, results were obtained that define the basic differences between the two types of hydraulic oil, HM and HV. In both cases, viscosity and density parameters values were compared before and after the oil filtration process under all press operating conditions, i.e., at different pressures and temperatures.

Based on the obtained results through the projection of the behaviour of hydraulic fluids, it is concluded that hydraulic oils of type HV perform much better at high temperatures, i.e., extreme conditions (temperatures from 70 to 100°C), while in normal conditions, i.e., temperatures up to 50°C, at different pressures of oil type HM better with basic parameters of viscosity and density. Considering the tribological properties and monitoring the leakage inside the components, the viscosity parameter is considered the most important characteristic of the fluid, so it can be said that taking into account the normal working conditions, HM oils proved better through performance. However, if there are potential larger leaks inside the components, this means that the heating of the oil will be faster because the intensity of using the same oil from the tank will increase, i.e., the installed coolers will not be able to cool the oil to the optimal temperature, in those conditions the oil that would be overheated are HV type oils.

Throughout this experimental inquiry, rigorous measures were implemented to facilitate research under optimal conditions, striving to minimize potential errors. However, it is crucial to acknowledge the inherent possibility of discrepancies inherent in any testing process, despite our concerted efforts to maintain precision and accuracy. Such recognition underscores the necessity for continual vigilance and critical evaluation in scientific investigations.

The hydraulic fluid filtration process can partially restore the performance of the oil compared to the contaminated oil, but the oil can never reach the performance of the new oil. The problem that can be isolated to a good extent is the presence of solid particles, which represents the greatest risk of damage to the interior of the components, which causes unacceptable leaks and directly affects the volumetric efficiency of the components.

Acknowledgments

The research is conducted through the project "Creating laboratory conditions for research, development, and education in the field of the use of solar resources in the Internet of Things", at the Technical Faculty "Mihajlo Pupin" Zrenjanin, financed by the Provincial Secretariat for Higher Education and Scientific Research, Republic of Serbia, Autonomous Province of Vojvodina, Project number 142-451- 3487/2023-01/01.

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