Research status of hydraulic oil evaluation technology

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Abstract. Hydraulic oil has an important influence on hydraulic system, and the research on its evaluation technology can provide technical support for the rational use of oil in hydraulic system. The status of hydraulic oil evaluation technology research at home and abroad is reviewed, including the physicochemical properties and comprehensive performance indexes of the oil. Combined with military requirements, it is found that the low-temperature cold start performance of hydraulic oil is more critical, but there is less research in this area. Therefore, this paper builds a cold start performance evaluation bench and test method to provide technical support for military oil use.

1. Introduction
The main role of hydraulic oil in hydraulic system is to transfer energy, as well as lubrication, anti-wear, cleaning, and rust prevention of components [1]. The correct and reasonable selection of hydraulic oil has an important impact on extending the service life of hydraulic systems and components and improving the reliability of the system. There are many performance indicators of hydraulic oil, including physicochemical performance indicators such as viscosity, shear stability, and seal adaptability, as well as operational performance indicators such as anti-wear and oxidation life [2]. With the increase of equipment load and the extension of oil change intervals, the oil performance requirements are getting higher and higher. Accordingly, the technical requirements for the evaluation of hydraulic oil is also getting higher. In this paper, the evaluation technology of hydraulic oil is reviewed in this context.

2. Physicochemical properties and evaluation
The physicochemical properties are important performance characteristics of the oil. By evaluating the physicochemical properties, we can have a comprehensive understanding of the oil and provide a reliable basis for the oil demand.

2.1. Oxidation stability
Oxidation stability refers to the ability of the oil to resist the action of the atmosphere or oxygen and keep its properties from permanent change. The gums and deposits generated by the oxidation of hydraulic oil will affect the normal operation of hydraulic components, and the acidic oxides generated will corrode the hydraulic components, so the hydraulic oil is required to have good oxidation stability. The oxidation stability of hydraulic oil is usually evaluated by GB/T 12581 "Standard test method for oxidation characteristics of inhibited mineral oils" [3] and SH/T 0193 "Lubricating oils—Determination of oxidation stability—Rotating pressure vessel method " [4].
2.2. Incompressibility and anti-foaming properties
The volume of the liquid is not easy to change under the action of external forces. However, dissolved air has a significant effect on compressibility. The anti-foaming property of hydraulic oil refers to the tendency and stability performance of the oil to generate foam. The incompressibility of hydraulic oil is evaluated by air release value, which is defined as the time required to reduce the volume of mist air in the sample to 0.2% under standard test conditions. The air release value is usually determined using SH/T 0308 "Determination of Air Release Value of Lubricating Oil" [5]. The anti-foaming property of hydraulic oil is generally expressed by the foam tendency/foam stability under certain conditions, which is determined by GB/T 12579 "Determination of foaming characteristics of lubricating oils" [6].

2.3. Shear stability
Shear stability refers to the ability of oil to resist shear and maintain its viscosity and viscosity-related properties unchanged. The shear stability of hydraulic oil is expressed by determining the percentage of decrease of its kinematic viscosity under a certain temperature condition. Commonly used test method is SH/T 0505 "Shear stability determination method for polymer oil" [7].

2.4. Seal adaptability
During the working process of hydraulic transmission, it is often accompanied by internal/external leakage problem. Internal leakage leads to instability and deterioration of the working condition of the transmission; external leakage causes the leakage of hydraulic oil and pollutes the environment. Therefore, it is required that the hydraulic oil be adapted to the seal material used to minimize leakage. SH/T 0305 "Petroleum Products Seal Adaptability Index Determination Method" [8].

2.5. Anti-emulsification and hydrolysis stability
The ability of oil and water to form emulsion is called emulsification; the ability of the emulsion formed by the oil and water to be divided into two layers is called anti-emulsification [9]. The ability of oil to resist water reaction when in contact with water is hydrolytic stability. The anti-emulsification property is evaluated by GB/T 7305 "Standard test method for water separability of petroleum oils and synthetic fluids" [10]; the hydrolysis stability is determined by SH/T 0301 "Determination method of hydrolysis stability of hydraulic oil" [11].

2.6. Anti-rust property
Anti-rust refers to the ability of oil to prevent rusting of the metal it comes in contact with, and is determined using GB/T 11143 "Standard test method for rust-preventing characteristics of inhibited mineral oil in the presence of water" [12].

2.7. Filterability
The development trend of hydraulic system is miniaturization, high power, high pressure, high temperature, high efficiency, etc. These trends will certainly make the circulation frequency of oil increase, which requires the oil to have better filterability and cleanliness. The filterability of hydraulic oil can be determined by SH/T 0210 "Hydraulic oil filterability test method" [13].

3. Anti-wear performance bench test
Current hydraulic oil bench tests are mainly focused on assessing the anti-wear characteristics of hydraulic oil, and a small number of bench tests can be used to assess oxidation life, energy-saving performance, etc. According to the category of hydraulic pumps in the bench test, the bench test can be divided into vane pumps and piston pumps.

3.1. Vickers 104C vane pumps test
The Vickers 104C vane pumps test was proposed by the OEM manufacturer Vickers, whose hydraulic system is shown schematically in Figure 1.
The test conditions of the bench are shown in Table 1.

| Test pressure (MPa) | Rotational speed (r/min) | Test temperature (°C) |
|---------------------|--------------------------|-----------------------|
| 13.8                | 1200                     | 77                    |

The scoring of this bench test is mainly based on the weight loss of the stator and vanes of the experimental pump [14]. The general anti-wear hydraulic fluid requires that the total weight loss of the stator and vanes after the 100h test should not be more than 100mg; the high-pressure anti-wear hydraulic fluid should not be higher than 50mg.

3.2. Komatsu HPV35+35 bench test
In accordance with the requirements of method P044 of the Japanese construction hydraulic oil JCMAS HK specification, a Komatsu HPV35+35 bench [15] was established. Intermittent pressure loading (maximum pressure is 34.3 MPa, one cycle every 5s) and high oil temperature (95±5°C) working conditions were used to collect the viscosity, acid value, water, and evaluate the oil every 100h of operation. The schematic diagram of the bench test is shown in Figure 2.

The test conditions of this stand are shown in Table 2.

| Test pressure (MPa) | Rotational speed (r/min) | Test temperature (°C) |
|---------------------|--------------------------|-----------------------|
| 34.3±0.5            | 2100±50                  | 95±5                  |

Figure 1. Schematic diagram of Vickers 104C bench test hydraulic system [3].

Table 1. Test conditions of Vickers 104C bench.

Figure 2. Schematic diagram of the bench [15].

Figure 3. T6H20C hybrid pump test flow chart [16].

Table 2. Test conditions of Komatsu HPV35+35 bench.
3.3. T6H20C hybrid pump test
The T6H20C hybrid pump test was proposed by Denison, USA, and the Denison specification to which it belongs is considered to be the most stringent hydraulic oil standard recognized in the petrochemical industry. The T6H20C hybrid pump test uses intermittent pressure loading, with alternating pressure loading between the vane pump and the piston pump every 2 s. The piston pump pressure is 28 MPa, and the vane pump pressure is 25 MPa, and the rotation speed is 1700 r/min. The double pump test is divided into two stages, the first for the water-free test stage, the inlet oil temperature of 110 °C, the test cycle of 300 h; the second test stage to add 1% (volume fraction) of deionized water, in the oil temperature of 80 °C in the operation of 300 h. Through the test process of oil viscosity, water, acid value, filterability and other physicochemical properties changes, as well as the wear condition of the friction pair after the test to comprehensively evaluate the anti-wear characteristics [16]. The schematic diagram of the bench test is shown in Figure 3, and test conditions are shown in Table 3.

Table 3. Test conditions of T6H20C hybrid pump.

| Test pressure (MPa) | Rotational speed (r/min) | Test temperature (°C) |
|---------------------|--------------------------|-----------------------|
| 25                  | 28                       | 1700                  |
|                     |                          | 110                   |
|                     |                          | 80                    |

4. Oxidation life bench test
With the development of hydraulic technology, the conditions of use of hydraulic system components have become more demanding and the requirements of hydraulic oil are higher, especially in terms of service life. The service life of hydraulic oil depends to a considerable extent on their oxidation life, and therefore the oxidation life assessment of hydraulic oil needs to be carried out.

4.1. A2F10 piston pump bench
The A2F10 piston pump bench system simulates the continuous operation test under the working conditions of engineering machinery and equipment such as working pressure and temperature [17], and examines the physicochemical indexes such as kinematic viscosity, acid value, sludge, oxidation stability, etc. to comprehensively analyze the oxidative deterioration trend of the oil and predict the service life of the oil. The schematic diagram of the bench test is shown in Figure 4.

4.2. Vickers 20VQ5 bench test
The Vickers 20VQ5 bench test was established by Huang Shengjun et al. to evaluate the oxidation durability of oil [18], which was used to conduct air entrainment tests at high temperature and pressure to evaluate the oxidation durability of oil by comprehensively investigating the viscosity, acid value and sludge of oil. The schematic diagram of the bench test is shown in Figure 5.

![Figure 4. A2F10 piston pump bench test hydraulic circuit diagram [17].](image)

![Figure 5. Schematic diagram of Vickers 20VQ5 test stand system [18].](image)
5. Low temperature cold start bench test

Due to the special operation conditions of military equipment, the cold start performance of the hydraulic oil needs to be evaluated to solve the practical problems of difficult or non-action of the equipment in extreme cold conditions. For example, it is found that hydraulic winch system appears the phenomenon of slow action or even non-action of the hydraulic valve system in Mohe (-43 °C). However, by reviewing the literature, there are few evaluation methods for the low-temperature cold startability and pumping capability of hydraulic oil. One of the existing methods related to low temperature [19] is mainly used to determine the stability of hydraulic oil at low temperature by turbidity and cannot determine the cold start performance of hydraulic oil at low temperature. Therefore, it is necessary to carry out research on the evaluation technology of the cold start performance of hydraulic oil at low temperatures and to establish a bench test and test method.

5.1. Test devices

Hydraulic oil in the working process will produce pressure loss, and the loss is related to the viscosity of hydraulic oil. The higher the viscosity, the greater the pressure loss. In the low temperature environment, due to the viscosity of the hydraulic oil increases, resulting in increased pressure loss. If the pressure of the hydraulic oil is not enough to overcome the pressure loss, it will lead to the control valve is difficult to open or hydraulic motor is difficult to turn, will produce hydraulic winch action is slow or cannot pull the phenomenon. But the low temperature viscosity of the hydraulic oil is not the smaller the better, the reason is that if the hydraulic oil is guaranteed to have a small viscosity under low temperature conditions, then the viscosity of the hydraulic oil under high temperature conditions is also small, and the low viscosity under high temperature conditions will lead to easy leakage of hydraulic system components, reducing the sealing and use of the hydraulic system.

Through the influence of hydraulic oil low-temperature viscosity on the performance of hydraulic system, the hydraulic oil low-temperature cold start performance evaluation bench shown in Figure 6. By simulating the actual working conditions of the hydraulic system and collecting the torque, speed, pressure, temperature and other parameters during the working process, the power delivery capacity of the hydraulic oil under low temperature conditions is evaluated.

![Figure 6](image)

**Figure 6.** Hydraulic winch system oil low temperature cold start evaluation test device.

5.2. Test methods

On the designed test bench, the test conditions shown in Table 4 were selected to evaluate the low-temperature cold start performance of hydraulic oil for military hydraulic oil, civilian hydraulic oil, and oil substitutes. The test procedure is shown in Table 5.
Table 4. Test conditions of designed test bench.

| Test temperature (°C) | Torque (N.m) |
|-----------------------|--------------|
| 25                    | 0            |
| -20                   | -40          |
| 12000                 |              |

Table 5. Test procedure.

| Steps | Operation |
|-------|-----------|
| 1     | Clean the system with test oil, measure the test oil and add it to the oil tank |
| 2     | Start the ultra-low temperature environment freezing chamber, make sure the test oil temperature reaches the test condition |
| 3     | Turn on the air compressor pump and make the gas pressure reach 0.9MPa to ensure the preload torque of the air hub can reach 12000Nm |
| 4     | Open the measurement and control program client and start data logging |
| 5     | Turn on the gear pump switch on the console and make the test oil circulate for 10s |
| 6     | Adjust the three four-way reversing valve to run for 20s after the torque between the planetary reducer and the brake hub reaches 12000Nm |
| 7     | Reverse adjust the three four-way reversing valve to make the friction torque 0Nm |
| 8     | Turn off gear pump, export data, end of test |

Parameters such as outlet pressure of oil pump, output power and temperature rise of hydraulic oil were collected as evaluation indexes. Figure 7 shows the test results with L-HM46, 8H and #15 hydraulic oil.

From Figure 7, it can be seen that all three evaluation indexes can effectively distinguish different test oils, which is sufficient to show that the bench test built and the selected evaluation indexes can effectively evaluate the low-temperature starting performance of the hydraulic oil.
6. Summary
With the development of hydraulic technology, the performance requirements of hydraulic oil are getting higher and higher, and the specifications and standards of hydraulic oil are constantly updated, which makes the hydraulic oil evaluation technology also need to be updated. At present, the evaluation of hydraulic oil mainly includes physicochemical properties evaluation, anti-wear performance evaluation and oxidation performance evaluation, etc. Among them, the evaluation of anti-wear performance is the most researched, and the relevant test benches include Vickers 104C vane pump test, Komatsu HPV35+35 bench test and T6H20C hybrid pump test, etc.

Due to the special characteristics of the military equipment use environment, in addition to the above assessment, also need to focus on the low temperature cold start ability of the hydraulic oil. However, there is less research in this area, and the existing low temperature research cannot meet the military needs. Therefore, this paper builds a bench test to evaluate the low-temperature cold start performance of hydraulic oil to provide a reference basis for the reasonable oil requirements of military equipment.

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