White Paper

Reliable Hydraulic System Operation Through Proper Fluid Selection & Maintenance

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Introduction

Hydraulic equipment can be found in factories, on earthmoving equipment, in cars and trucks, on airplanes, and even in medical offices and hair salons. Hydraulic systems on equipment are employed to perform all types of duties: large or small, sensitive or harsh, and precise or imprecise. The science of hydraulics relies upon the use of pressurized liquid to transmit power. This transmission of power in equipment is used to perform work, such as lift, haul, dig, turn, mold and shape.

The premise for simple hydraulic systems was set forth in the 1600s by Blaise Pascal, when he said that a force applied at one point is transmitted to another point by using an incompressible fluid. The fluid is almost always a type of oil. Yet, depending upon the application, numerous base fluids can be employed as the incompressible fluid.

For marketing purposes, hydraulic fluids are classified in various ways. The two major hydraulic fluid class descriptions are mineral oils or synthetics, based upon the major ingredient – the base fluid. Typically, most users tend to call both of these types "oil."

This paper will describe how hydraulic fluids are classified for various types of equipment and how these classifications are used to ensure that the proper fluid is chosen. It will also explain how specific attributes affect the performance of the oil. After the hydraulic fluid is chosen, a variety of storage, handling and maintenance routines must be practiced to maximize reliable and efficient equipment operation.

Classification of Hydraulic Fluids

Eventually, a hydraulic system user will have to change the fluid in the system. The first few questions that may arise are, "What do I fill this system with?" and "How do I know what I am looking for?" After a quick Internet search, the user may be stymied, as the number of hydraulic fluid options available is almost overwhelming. At that point, it is very helpful to know and understand how hydraulic fluids are classified. This paper is intended to help hydraulic system users simplify this seemingly overwhelming task by explaining hydraulic fluid classifications. Table 1 shows the six major categories for classifying hydraulic oils. Each will be described subsequently.

Table 1: Hydraulic Oil Classifications

Application (choose one)	Mobile
	Industrial
Special Requirements (if any) (choose any combination)	Fire-resistant
	Environmentally friendly
	Food-grade
Performance Level (choose one)	Basic "fighting grade"
	General purpose
	Premium

Base Fluid (choose one)	Mineral oil
	Synthetic
	Biobased
Additives (choose any combination)	R & O
	Anti-wear (ashless, zinc-containing or extreme pressure)
	Detergent/dispersant
	Viscosity improver
Viscosity (choose one)	Straight grade
	Multigrade

Application

First, hydraulic fluids are classified based upon the application for which they will be used. The main application classes are mobile and industrial, describing whether the fluid is for use in moving equipment or stationary equipment. The ingredient selection process for hydraulic products can be limited depending upon the application type in which the fluid will be used.

Top: *A crane is an example of equipment that uses mobile hydraulic fluid.*

Left: *Machines such as this one on a factory floor use industrial hydraulic fluid.*

Mobile hydraulic fluids, as the name suggests, are ones that are designed for applications that move, such as tractors, cranes, cherry pickers and various types of construction equipment. Industrial hydraulic fluids are employed in equipment used in industrial settings, such as factories, where the hydraulic system operates in a specific work area. The same fluid chemistries can be used for certain mobile and industrial equipment because many original equipment manufacturers (OEMs) of hydraulic systems build them for both types.

Special Requirements

Fire-resistant, environmentally friendly and food-grade could be considered subclasses of the industrial and mobile types.

Fire-resistant hydraulic fluids must be formulated using very specific synthetic base fluids and additives, because they are used on equipment that is operating near a flame source. All mineral oil and some synthetic-based fluids can catch fire if a hose springs a leak. In some cases, users are required to purchase a fluid that has been approved by Factory Mutual, a global insurance company that evaluates hydraulic fluid product formulas and approves them, and warrants their use in high risk plants.

Fluids that are marketed as environmentally friendly means the ingredients are either biodegradable, low-toxicity, bio-based, recyclable, or combinations of all of these.

Food-grade hydraulic fluids are approved for incidental food contact (not direct inclusion in food), which means the additives and base fluids have met food-grade lubricant requirements. For many years, the U.S. Food and Drug Administration (USDA) granted approvals for these lubricants. The USDA no longer provides these approvals, but other organizations – such as NSF International – are offering either food grade product registration or certification for an ISO standard that requires plant inspections and product ingredient reviews.

Performance Level

Next, hydraulic fluids can be classified by performance, with the choice of three levels: basic (fighting grade), general purpose or premium.

Basic hydraulic fluids are designed to be inexpensive. Often, these products are produced using the least expensive ingredients that can be sourced and might include minimal additive treat rate levels, or perhaps slightly off-spec raw materials. This does not mean that these are bad products when used for specific applications. For example, if a hydraulic system has major leaks and the oil will not stay in the system very long, then a high-priced formula does not make sense.

The majority of hydraulic fluid volume falls into the general purpose classification. These are products that are formulated to meet the non-severe service specifications of most OEMs.

Finally, certain OEMs require specific high-performance fluids for their equipment, and these are called premium hydraulic fluids. In most cases, the user will find that the price of oil goes up dramatically from fighting grade, to general purpose, to premium grade.

Base Fluid

The fourth way that hydraulic fluids are classified is by their base fluid type, which makes sense considering the base fluid is the largest volume ingredient in all hydraulic fluid formulations.

Due to the use of newer refining technologies, along with ever increasing requirements by OEMs, hydraulic base fluid choices by formulators have changed over time. In 1993, the American Petroleum Institute (API) produced *Publication 1509 Engine Oil Licensing and Certification System*, which provided a framework upon which engine oils could be classified. Table 2 shows these base stock categories. [1]

Table 2: API Paraffinic Base Stock Categories

Group	Sulfur, Mass %	Saturates, Mass %	Viscosity Index
I	>0.03	<90	≥80 to <120
II	≤0.03	≥90	≥80 to <120
III	≤0.03	≥90	≥120
IV	All Polyalphaolefins		
V	All stocks not included in groups I-IV		

It is becoming more and more common to identify lubricating base fluids by their API classification. This same classification system has been extended to describe finished lubricants, including hydraulic fluids.

Today, many lubricant formulators will reference these categories when formulating hydraulic and other industrial oils.

Additives

Hydraulic fluids are also classified often based on the additive protection that they offer. [2] These include: Rust and oxidation (R & O), anti-wear (AW), detergent/dispersant and viscosity improvers. Ashless, zinc-containing and extreme pressure (EP) are sub-classifications of anti-wear oils. Oils containing detergent and dispersant additives are used for equipment in dirty environments or in combined hydraulic and engine applications. Viscosity improvers are added to some formulas to give them broader operating temperature properties. Table 3 provides a brief description of these and other additive types used in various hydraulic fluids.

Table 3: Hydraulic Fluid Additives – Function & Chemical Type

Additive	Purpose	Function	Typical Compounds
Rust Inhibitor	Prevent or reduce rusting	Preferential adsorption of polar, surface-active materials, neutralize corrosive acids.	Sulfonates, amines, fatty oils, oxidized wax, and halogenated ferivatives of some fatty acids.
Oxidation Inhibitors	Prevent varnish and sludge formation, extend fluid life 10 to 100 times	Terminates oil oxidation by the formation of inactive compounds or by oxygen scavenging	Organic compounds containing sulfur, phosphorous, or nitrogen such as: zinc dithiophosphates, organic sulfides and thiophosphates, hindered phenols and alkylated aromatic amines.
Corrosion Inhibitor	Prevent corrosive attack on alloys or other metallic surfaces.	Inhibits formation of acidic bodies or forms a protective film over metallic parts.	Organic compounds containing sulfur, phosphorous or nitrogen such as phosphites, metal salts of thiophosphoric acid and terpenes.
Pour Point Depressant	Lower the pour point temperature	Modification of wax crystals to prevent growth with accompanying solidification at low temperatures.	Alkylated naphthylene or phenols and their polymers, methacrylate polymers.
Anti-foamant	Prevent formation of stable foam and entrained air which may increase compressibility.	Change interfacial tension to permit bubble coalescence into larger bubbles which separate faster.	Silicone polymers, organic polymers (acrylate esters).
Anti-wear (AW) Agent	Reduce wear	Forms a film on metallic contacting surfaces.	Organic phosphates and phosphites, zinc dithiophosphate.
Oiliness Agent (Boundary Lubrication Additive)	Reduce friction under near-boundary conditions.	Adherence of polar materials to metal surfaces.	High molecular weight compounds such as fatty oils, oxides, waxes or lead soaps.
Extreme Pressure (EP) Additive	Prevent galling, scoring and seizure.	Formation of low shear films on metal surfaces at point of contact.	Sulfur, chlorine, phosphorous containing materials.

Detergent	Keep surfaces free of deposits.	Chemical reaction with sludge and varnish precursors to neutralize them and keep them soluble.	Metallo-organic compounds of barium, calcium and magnesium phenolates, phosphates, and sulfonates.
Dispersant	Keep insoluble contaminants dispersed.	Contaminants are bonded by polar attraction, to dispersant molecules, preventing agglomeration and kept in suspension due to solubility of dispersant.	Polymeric alkylthiophosphonates and alkylsuccinamides.
Viscosity Improver	Lower the rate of change of viscosity with temperature. Index (VI) Improver	Because of the solubility differences, viscosity is increased more at high temperature than at low temperatures.	Polymerized olefins or iso-olefins, butylene polymers, alkylated styrene polymers, polymethacrylate.

R & O hydraulic oils are formulated with naphthenic, paraffinic, synthetic or mixed-base oils. They generally contain only those additives that impart improved rust prevention and oxidation resistance to the base fluids.

AW oils are formulated with naphthenic, paraffinic, synthetic or mixed-base oils. These will usually be described as ashless or zinc-containing anti-wear hydraulic fluids. Although they contain additives for anti-wear, they will also still contain additives to provide R & O resistance. Zinc-containing AW hydraulic oils contain an additive called ZDDP (zinc dialkyldithiophosphate). Ashless AW hydraulic oils are formulated without zinc-containing components. Instead, the AW component in these formulas is comprised of phosphorus, nitrogen and sulfur-containing species.

Another classification sometimes used to describe AW hydraulic oils is EP. These oils are usually formulated using more active sulfur chemistries and provide lubrication to both the hydraulic system components and machine-tool ways to prevent stick-slip operation. Common examples of this type of hydraulic fluid are way lubricants and some tractor hydraulic fluids that are used for axle and transmission lubrication along with hydraulic system lubrication. [2]

Detergent oils are used in mobile equipment and robotic applications used in dirty environments. Some are used in combination engine and hydraulic service. These fluids exhibit a high viscosity index and are suitable for use over a broad range of temperatures. They are typically formulated to provide R & O protection and to clean and disperse contaminants. Examples are tractor hydraulic fluids and automatic transmission fluids. Either of these types of fluids can be used in hydraulic systems if it is known that detergency is needed to keep the system clean.

Viscosity

Hydraulic fluids are sometimes classified by viscosity as either straight-grade or multigrade. As has been noted previously, sometimes viscosity improvers are added to increase the viscosity index of oil, which results in expanded operating temperature ranges.

Straight-grade oils are often classified according to ASTM D2422 “Viscosity System for Industrial Fluid Lubricants,” which is also known as the ISO Viscosity Grade Scale. [3, 4] The viscosity classification system is provided in Table 4. It should be noted that not all of the viscosity grades noted in this table are commonly used in hydraulic fluids. This classification system only provides information on the viscosity at 40°C. Viscosities at other temperatures are dependent on the viscosity index properties of the fluid.

Table 4: Viscosity System for Industrial Fluid Lubricants (ASTM D2422)

ISO Viscosity Grade	Kinematic Viscosity Limits cSt(mm^2/s) at 40°C		
	Midpoint	Minimum	Maximum
ISO VG 2	2.2	1.98	2.42
ISO VG 3	3.2	2.88	3.52
ISO VG 5	4.6	4.14	5.06
ISO VG 7	6.8	6.12	7.48
ISO VG 10	10	9	11
ISO VG 15	15	13.2	16.5
ISO VG 22	22	19.8	24.2
ISO VG 32	32	28.8	35.2
ISO VG 46	46	41.4	50.6
ISO VG 68	68	61.2	74.8
ISO VG 100	100	90	110
ISO VG 150	150	135	165
ISO VG 220	220	198	242
ISO VG 320	320	288	352
ISO VG 460	460	414	506
ISO VG 680	680	612	748
ISO VG 1000	1,000	900	1,100
ISO VG 1500	1,500	1,350	1,650

Multigrade oils are usually used in mobile hydraulic applications, where dramatic temperature variations could be experienced. In these cases, the fluids are sometimes recognized by SAE viscosity grades described in the SAE J300 Viscosity Classification (shown in Table 5). As this table indicates, these categories require specific performance at high and low temperatures, thus the term “multigrade.” The important thing to point out is that the kinematic viscosity measurement is conducted at 100°C (212°F) in contrast to 40°C (104°F) for industrial oils. It is also important to note that not all of these grades are commonly used to classify hydraulic oils. Multigrade hydraulic oils will have to be formulated using either synthetic or mineral oil base fluids, along with viscosity index improvers, or the oils will not meet both high- and low-temperature requirements.

Table 5: SAE J300 Viscosity Classification

SAE Viscosity Grade	Low-Temperature Viscosities *Cranking[b] (mPa.s) max at temp °C (°F)*	High-Temperature Viscosities *Pumping[c] (mPa.s) max at temp °C (°F)*	Kinematic[d] (mm²/s) at 100°C (212°F)		High Shear[e] Rate (mPa.s) at 150°C (302°F)
			min	max	min
0W	6,200 at -35 (-31)	60,000 at -40 (-40)	3.8	—	—
5W	6,600 at -30 (-22)	60,000 at -35 (-31)	3.8	—	—
10W	7,000 at -25 (-13)	60,000 at -30 (-22)	4.1	—	—
15W	7,000 at -20 (-4)	60,000 at -25 (-13)	5.6	—	—
20W	9,500 at -15 (5)	60,000 at -20 (-4)	5.6	—	—
25W	13,000 at -10 (14)	60,000 at -15 (5)	9.3	—	—
20	—	—	5.6	<9.3	2.6
30	—	—	9.3	<12.5	2.9
40	—	—	12.5	<16.3	2.9
40	—	—	12.5	<16.3	3.7
50	—	—	16.3	<21.9	3.7
60	—	—	21.9	<26.1	3.7

Hydraulic Oil Properties

Thus far, it has been pointed out how hydraulic fluids are classified. It is also important that hydraulic fluids have properties that provide specific performance attributes. Knowledge of the properties of a hydraulic oil formulation is important to the OEM for design and operation of a hydraulic system. These properties include viscosity, pour point, gas solubility, demulsibility, filterability and oxidation stability, in addition to various thermal and electrical properties. [3, 5] In this section, the importance of these properties will be described.

Viscosity

Viscosity is the single most important physical property exhibited by a hydraulic fluid. If the hydraulic fluid viscosity is too high:

1. Flow resistance will be increased as the fluid passes through the clearances in the pump and valves.
2. System temperature will increase due to lack of lubrication.
3. System operation will then become sluggish.
4. There will be an increased pressure drop in the system.
5. In the end, power consumption will increase.

A viscometer is used in a laboratory to measure a hydraulic fluid's viscosity. (resistance to flow).

If the fluid viscosity is too low:

1. Internal and external leakage will increase.
2. Pump slippage will increase, causing reduced efficiency and increased temperatures.
3. Wear rate will increase due to thin hydrodynamic film strength of the fluid.
4. Pressure loss will occur, which will result in loss of system control. [6]

The maximum fluid viscosity for proper pump operation is dictated by the hydraulic pump design and is therefore manufacturer-specific.

Pour Point

The pour point is the lowest temperature at which the fluid will flow. [3] It is an important consideration for a fluid that will be used in mobile equipment that is kept outside in cold weather. The oil used in such operations must have a pour point below the lowest startup temperature anticipated. However, pour points must be considered along with the pump manufacturer's highest recommended startup viscosity. [7]

Gas Solubility

It is obvious that hydraulic fluid is a liquid. Because the fluid is constantly in motion within a hydraulic system, it is possible for gas to become mixed with the fluid. In general, the most common gas that will get mixed into systems is air. When the concentration of air in a hydraulic system exceeds the saturation level, the gaseous bubbles are suspended in the hydraulic fluid. Air entrainment must be minimized for proper fluid performance in the hydraulic pump. When entrained air accumulates within a hydraulic fluid, it eventually reaches a point where it tries to dissipate out the top of the fluid surface. Depending on the surface tension properties at the air oil interface, oil-encased gas sometimes collects on the oil surface and forms foam on the fluid surface. Excess foam can arise from various sources including fluid contamination, poor reservoir design and the formation of metallic soaps such as might be formed from reaction of additives in the fluid. [7]

Roberton and Allen performed a detailed analysis of the potential for hydraulic system variables to promote oil oxidation, thermal cracking and nitration. [8] Their conclusions were:

1. Fluid aeration was the major factor contributing to accelerated oil degradation processes. Constant volume hydraulic pump systems with short residence times were the most prone to exhibit oil degradation and servo-valve problems.
2. These problems could be modeled in the laboratory and were correlated to fluid air entrainment.
3. It is unlikely that laboratory bench tests for oxidation or thermal stability can completely assess the capabilities and limitations of a hydraulic fluid in the pump.
4. To minimize potential oxidative degradation, thermal cracking and nitration problems with respect to hydraulic pump and servo-valve performance, it is important that optimal separation of the entrained air be promoted, usually by the addition of an air release additive.

Demulsibility

Water contamination of hydraulic fluids can occur when there is a humid atmosphere above the hydraulic fluid in the reservoir, constant air leakage into the hydraulic circuit, or seepage of the heat exchanger coolant into the hydraulic fluid. [9] The contaminated oil may then form an emulsion produced by the high fluid shear motion in a hydraulic pump that churns together the fluid and water. [10]

Hydraulic systems contaminated by water may lead to numerous other problems such as:

- "Thin and watery" or "thick and pasty" fluids
- Dirt and dust contamination
- Increasing occurrence of valve malfunction
- Increasing wear and corrosion
- Oil oxidation
- Additive depletion
- Foaming and filter plugging [10, 9]

Therefore, all possible attempts should be made to keep water contamination out of a hydraulic pump. If water contamination occurs, it must be removed as soon as possible.

Highly refined mineral oils are hydrophobic. However, additives and oil oxidation byproducts such as acids may promote the emulsification of water in the fluid. An early test for water contamination enhanced by oil oxidation involved the measurement of the surface tension of the fluid. It was proven that as the fluid aged and oxidation occurred, surface tension of the fluid decreased. [9] Oil replacement is recommended when the surface tension is ≤15 dyne/cm.

Filterability

Very tight clearances are present within most hydraulic systems. Therefore, it is important that the fluid be capable of filtration. Filtration is often employed to remove contaminant debris from the fluid before it gets between the moving parts in the pump, resulting in accelerated wear or the plugging of the sensitive servos and valves in the controls, making the operation jerky. Yet, it is important to realize that some hydraulic fluids are formulated to contain additives (such as viscosity modifiers [11] and defoamants), which exist as very small particles in the fluid. Although these particles may not be visible to the naked eye, they can be removed by high-efficiency, fine (<3µ) filtration. [12] These fine particles will actually cause plugging of the filters. Therefore, it is desirable to evaluate the filterability of a hydraulic fluid as both a measure of potential filter plugging and additive removal.

Oxidation Stability

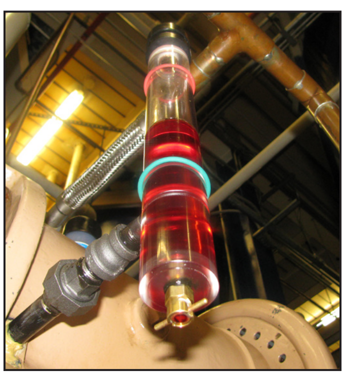
Oxidation stability refers to the "ability of hydraulic fluid to resist polymerization and thermal decomposition in the presence of air, water, heat and dissimilar materials." [13] Additional variables that affect oil oxidation rates include: ambient temperatures, atmospheric conditions, contamination, oil viscosity, type of pump, pump pressures, and pressure cycling. [14] Oil decomposition products are either soluble or insoluble. Soluble oil degradation products generally thicken the oil. [15] Insoluble products form sludge deposits in the oil which can lead to filter clogging, valve and piston sticking, hydraulic lock [16, 17, 18], increased wear, and corrosion. [15] Oil degradation byproducts, water, wear debris, and corrosion debris often catalyze the overall oxidative degradation process.

The oxidation stability of hydraulic oil can be largely a function of the base fluid selected. For example, paraffinic oils exhibit better oxidation stability than naphthenic oils and various synthetic base fluids may have better oxidation stability than mineral oils. Temperature has the greatest impact on oxidative stability. On the basis of temperature-viscosity performance, optimum fluid temperature ranges are often between 32-71°C (90-160°F). [13] Some of the greatest thermal stress on the fluid may occur in valves where the fluid is forced through small orifices at high velocities. It has been shown that even at oil temperatures as low as 38°C (100°F) the presence of varnish deposits on valves have indicated the presence of localized temperatures in excess of 93°C (200°F). [14] Foaming and air entrainment increase oxygen contact with the fluid and therefore accelerate oxidative degradation. Backé and Lipphardt showed that under proper conditions pressure increases dramatically, reduces the bubble size, and increases the temperature enough to cause ignition at the air-bubble/oil interface. This is called the “micro-dieseling effect.” [19] Using calculations, it was found that ignition would occur when the temperature on the bubble surface was typically 340-360°C (644-680°F).

Although the terms “rusting” and “corrosion” are often used interchangeably, they are fundamentally different processes with different fluid formulation challenges. [14] Rusting is caused by the reaction of water and air with a ferrous surface in the hydraulic system. [20] Corrosion can be caused by the reaction of organic acids, in the presence of peroxides, both originating from oxidation of the hydraulic oil. [13] Corrosion can also be caused by overly active additives. For example, some sulfur-containing wear reduction additives can produce a harmful, dark, sulfide layer on copper parts in hydraulic systems. As mentioned in a previous section, rust and corrosion can be controlled using the proper choice of additives, including antioxidants and metal deactivators.

Fluid Condition Monitoring

Several things must be done to ensure reliable hydraulic fluid performance. The first thing may seem obvious, but it is important to verify that the proper fluid levels are maintained within the piece of equipment. This is done by periodically checking the oil via a dipstick or visually looking into the sump through the fill spout. Today many users are installing devices called sight glasses that allow the operator to simultaneously see the product level, appearance, foam content and possible water contamination.



Next, it is important to keep the fluid clean. This can be done in several ways. One way is to remove contamination or keep it out of the system in the first place. One of the most popular ways to remove contamination is to use filtration. Other techniques that can be used to keep contamination out of the system include air breather filters and desiccators.

Even when sight glasses and filtration are employed, it is possible to have things going on within the oil that can only be noticed through a more thorough evaluation. To do this, many perform periodic analysis of in-service hydraulic oil as part of a reliability maintenance program to optimize performance and minimize downtime.

There are two primary reasons for performing oil analysis. The first is to determine if the oil quality is acceptable for continued use. The second is to assist in determining the root cause of problems within the hydraulic system or one of its components. [21] Both of these are often called condition monitoring, because the oil analysis is used to determine the condition of the oil and the hydraulic pump system while in-service.

Various factors may affect the useful life of hydraulic oil. Some of the most common factors are summarized in Table 6. [21]

Table 6: Major Factors Influencing Useful Hydraulic Oil Lifetime

Problem	Fluid Response
Excessive operating temperature and system hot spots	Viscosity increase due to fluid degradation accompanied by presence of acidic byproducts that promote corrosion. Sludge and varnish formation reduces heat transfer and causes actuator malfunction.
Contaminants	
Water	Catalyzes fluid oxidation, promotes rusting and may lead to emulsification of the fluid, which will lead to a reduction of lubricant effectiveness.
Airborne dirt and debris	Increase wear due to abrasion.
Metalworking fluids	May promote sludge or corrosion.
Foaming and aeration	Cause poor lubrication and sluggish hydraulic system response.
Wear metals	Promote fluid oxidation, cause abrasive wear and may stabilize the formation of oil-water emulsions formed by water contaminants.

Fluid Sampling

Hydraulic fluid samples should always be collected from a system while it is running and at operating temperature. A sample should be taken using a hand-pump or large syringe with a sufficient length of tubing to collect the sample from the middle of the reservoir. Routine sampling should not occur when oil is drained, from low spots in the system, or after the system is shut down for more than two hours. [22] If a sample is collected from the pressure line, at least one quart of fluid should be flushed from the system prior to actually collecting the sample. To ensure sample accuracy, it is critical that all sampling equipment and bottles be scrupulously clean prior to sample collection. [22]

The appropriate sampling frequency should be determined based upon the operating environment and system conditions. Initially, it could be weekly, then decreased to an appropriate level based on the results from the testing. Certain routine testing, such as fluid cleanliness, water content and viscosity could be done more frequently, and a detailed analysis performed at less frequent intervals or as needed. [22]

Basic Fluid Analysis Tests

A basic list of the tests that should be conducted on used hydraulic oil includes various physical and chemical tests such as: clarity, color, odor, water, viscosity, differential infrared analysis, insolubles, elemental analysis, foaming/air entrainment. [21]

Clarity, Color and Odor

The first few tests in the list are actually physical observations. They can be performed in a laboratory, but might even be conducted while the oil is in operation by the operator or sample collector.

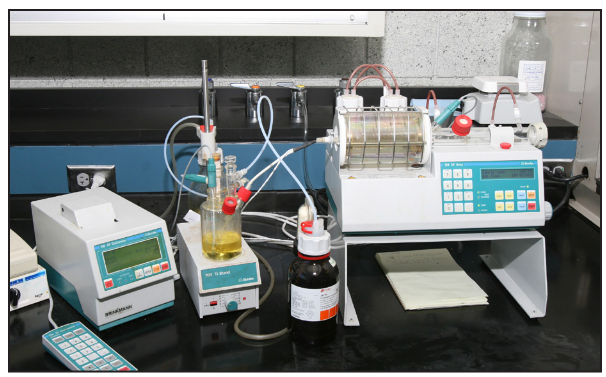
Fluid clarity is the first observation that is made in hydraulic fluid sampling. Uncontaminated or thermally abused fluid should be clear. Haziness or cloudiness is indicative of contamination, often by water or a water-containing source.

Color is perhaps the second observation. Sudden changes in color could be indicative of fluid contamination or degradation. For example, an increase in fluid darkness could be indicative of oil oxidation. The formation of sediment or sludge in the oil either due to contamination or degradation could result in a color change caused by the formation of a temporary suspension of small particulates within the oil.

The third physical observation is odor. Most hydraulic oils will have a certain distinctive odor when new, usually based upon the mixture of ingredients that make it up. Certain chemicals could be used near the hydraulic system that could be drawn in as contaminants that might change the odor of the oil while in service. Oil degradation, such as oxidation is typically accompanied by a rancid or pungent odor (burned fluid odor). [21, 23] Other sources of odor may be contaminants such as flushing fluids or strong sulfur odor which may arise from contamination by other fluids such as flushing fluids. [21]

Water

Hydraulic systems have the opportunity to draw significant quantities of water into the reservoir through the breather and other sources. Once drawn in, the hydraulic oil may absorb some of the water. Because oil and water do not mix, at a certain point oil contaminated with water will take on a hazy appearance. In this case, the visual inspection noted above will provide a strong indication of water contamination.



The Karl Fisher titrator is the most accurate laboratory test for measuring the amount of water contamination in hydraulic oil.

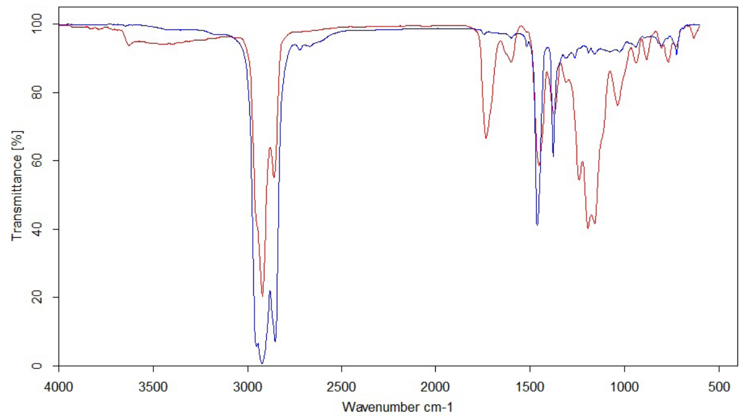
Water contamination of hydraulic oil may result in metal corrosion, bearing wear, and fluid oxidation. Fluid oxidation reduces the fluid’s lifetime by as much as 70 percent, and it affects component operation. [24] One common source of water contamination is ingression through the reservoir’s breather pipe. Generally, water concentrations should not exceed 200-300 ppm. [24] The test of choice for evaluating water in hydraulic fluids is the Karl Fischer method.

Viscosity

A change in the fluid viscosity may be an immediate indication of a system problem. Fluid viscosity may be determined by ASTM D445 (kinematic viscosity in centistokes (cSt). [25] Low viscosity values usually indicate contamination with a lower viscosity oil or solvent but could also indicate additive deterioration. [21] Higher viscosity values indicate contamination by a higher viscosity oil or water, but could also result from oil oxidation. [22] It is essential that the fluid viscosity be maintained within the hydraulic pump manufacturer’s limits.

Differential Infrared Analysis

One of the common tests used to evaluate hydraulic fluids is infrared analysis (IR), which shows the organic molecules, comprised of carbon, hydrogen, oxygen and nitrogen. The IR technique employed by most laboratories to analyze lubricant samples is Fourier transform infrared spectroscopy (FTIR). FTIR produces a spectrum – or "fingerprint" – that shows most of the fluid's ingredients. Using differential analysis, FTIR can be used to determine changes to the organic structure of the fluid and additives, such as oxidative degradation and contamination with other organic compounds, including other lubricants. What this means is that a sample is collected from an in-service piece of equipment and analyzed using FTIR. The same thing is done for new oil that has not been put into service, and the two fingerprints are compared. If the in-service oil appears to be badly contaminated or degraded, a decision can be made to either continue using the oil or perform service.



This FTIR image is a comparison of two hydraulic fluid samples: new (blue line) vs. used (red line). The difference in the two lines indicates the amount of oil degradation or contamination.

Insolubles

Insoluble debris can collect in hydraulic fluid as a result of either ingestion of external contamination, degradation of the fluid, or equipment wear. To ensure optimal performance of a hydraulic system, it is imperative that insoluble contaminants be removed from the system. There are two types of insoluble contaminants, hard and soft. Hard contaminants would include ingested dirt and equipment wear, while soft contamination is generally oil degradation byproducts.

Several tests are used to evaluate insoluble debris. One that is commonly used is ASTM D893 Standard Test Method for Insolubles in Used Lubricating Oils. In this test, the oil is weighted into a flask and dissolved in pentane or hexane. This mixture is then vacuum-filtered and rinsed with clean solvent. The filter is weighed to evaluate the pentane or hexane insolubles, including oxidative debris, dirt, fibers and wear metal. The same filter is then rinsed with toluene, which dissolves the oxidative debris and leaves behind only the inorganic contaminants, which are then weighed. The data from these two tests can be used to decide if the fluid should be changed, filtration can be used, or if the machine is in a catastrophic wear mode.

Elemental Analysis

While FTIR indicates the condition of the organic part of the fluid, elemental analysis can be used to evaluate the inorganic, or metallic, composition of the sample. The used hydraulic fluid or the ash residue obtained from ASTM D482 or ASTM D874 can be analyzed for elemental content using emission, atomic absorption (AA) or induction-coupled plasma (ICP) spectroscopy [26, 27]. ICP is the most commonly used method today. The elemental content can provide insight into the source of residue as shown in Table 7. [21]

Table 7: Sources of Elemental Residue in Hydraulic Fluids

Element	Sources
Aluminum, silicon	Dust and airborne dirt
Boron, potassium, sodium	Coolant inhibitor residues
Calcium, magnesium	Hard-water
Calcium, sodium	Saltwater (brine)
Chromium, copper, iron, zinc, lead, tin	Wear, corrosion or assembly debris
Barium, calcium, magnesium, phosphorous, zinc	Engine oil additives

Foaming/Air Entrainment

Used hydraulic oils that have either been contaminated or that have undergone oxidation are more susceptible to foaming and air entrainment. Foaming and air entrainment first and foremost lead to "spongy" hydraulic control due to increased fluid compressibility but also result in accelerated oxidation rates which lead to increased susceptibility to sludge and varnish.

Fluid Cleanliness

It is generally accepted that controlling fluid cleanliness is vitally important to reliable operation and reduced maintenance of hydraulic systems. [28, 29] One form of analysis of fluid cleanliness is particle counting. One of the most common particle tests is the ISO 4406 procedure which uses a light blockage technique to measure and quantify the particles in a sample of hydraulic oil. In this procedure, it is common to present a three digit code. The code is based upon the particle counts collected at 4-, 6- and 14-micron average diameters.

Another particle analysis technique is ferrographic analysis. There are two types of ferrographic analysis, direct reading ferrography and analytical ferrography. Direct reading ferrography is used to produce a trend line analysis of large and small ferrous (magnetic) particles present in the sample. Analytical ferrography is a more qualitative technique. In this technique, debris is removed from the sample and deposited on a test slide. The debris on the slide is then analyzed under microscopic magnification to evaluate the actual condition of the pump (in contrast to most of the other tests that were used to evaluate the oil condition).

System Fluid Replacement, Recycling & Reclamation

When hydraulic oil is in service it is possible for wear metals, environmental contaminants, and oil-oxidation films and deposits to build up in the hydraulic system. It is therefore necessary to periodically clean the system and replace the hydraulic oil. If deposits are films or light emulsion coatings on the metal surfaces then the system can usually be cleaned by flushing. [30]

Hydraulic system flush involves draining the used oil from the system, filling it with flushing oil, running it unloaded to splash the cleaner oil around in the system, then draining and refilling the system. However, if substantial buildup and deposits are formed, then the system will have to be dismantled and cleaned manually.

There has been increasing interest in extending the lifetime of hydraulic oils. The reasons for this include: conservation of natural resources (petroleum crude oil), decreased environmental liability for waste oil, reduced disposal costs, desire for fewer oil purchases, relatively low cost of reclamation, and excellent quality control procedures available. [31]

The primary processes for reclaiming used hydraulic oil include: recovery for use as fuel, re-refining, oil laundering and onsite reconditioning. [32]

Conclusion

It is unrealistic to suggest that this white paper does complete justice to the expanse of available knowledge covering the subject of hydraulic fluids. In fact, whole books have been written on the subject, and this author recommends the *Handbook of Hydraulic Fluid Technology* for more in-depth information. [33] Instead, the intent of this paper is to provide a basis of knowledge that makes it easier for a person new to the hydraulic power field to optimize equipment reliability through proper fluid selection, monitoring and maintenance.

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