

# Selecting fluids for hydraulic pumps

Anjeeve George  
Lead Engineer –  
Lubricants  
Eaton India  
Engineering Center

## Introduction

Hydraulic fluid is one of the most important components of a hydraulic system. It performs multiple functions, such as power transmission, lubrication, heat transfer, and conveyance of sludge, wear debris, and contamination.

With the important roles played by fluids, proper fluid selection is critical in maximizing performance and life of hydraulic pumps, motors, and other components. To make the right choice, a variety of fluid properties must be considered, along with other factors such as operating parameters, system requirements, environmental conditions, and regulations.

## How Fluids Affect Pump Performance

Hydraulic components and the hydraulic fluid work together to run the hydraulic system. Because the fluid is the medium by which power is transmitted to perform any usable work, hydraulic systems simply cannot operate without sufficient fluid.

With the critical role of hydraulic fluid, appropriate fluid type, viscosity, and quality are essential requirements for fluid selection. A hydraulic system with a poorly matched fluid may operate, but deliver substandard performance, and ultimately could lead to catastrophic failures. Improper fluid selection can cause various undesirable results, such as decreased system efficiency, lack of lubrication, reduced fluid and component life, corrosion, erosion, sludge and varnish formation, and excessive heat generation.

In addition to fluid properties and quality, contamination also affects system performance significantly. Contamination can generally originate from four sources: contaminated oil, built-in contamination, ingressed contamination, and internally-generated contamination. It can lead to decreased efficiency, component wear, and other adverse impacts. Studies indicate that more than 70 percent of hydraulic system failures are due to contamination and can reduce hydraulic efficiency as much as 20 percent before a system malfunction is recognized[1].

## Fluid Properties to Consider

Various fluid properties affect the fluid's ability to perform different functions. Viscosity, which describes a fluid's resistance to flow, is the most important. It accounts for hydrodynamic/boundary lubrication, volumetric efficiency, mechanical efficiency, cavitation, quantity of lubricants reaching lubricated parts, heat generation, and many other properties like air release, heat dissipation, and filterability.

Low viscosity fluids provide thin film thickness, leading to boundary lubrication conditions, which can result in metal-to-metal contact and damage system components. For example, when two moving metal surfaces contact each other with inadequate lubrication, excessive wear can occur due to cold welding, as shown in Figure 1, and damage components. Low viscosity also reduces volumetric efficiency of pumps and motors through increased internal leakages.



**Figure 1. Low viscosity can allow metal-to-metal contact and lead to damaged components.**

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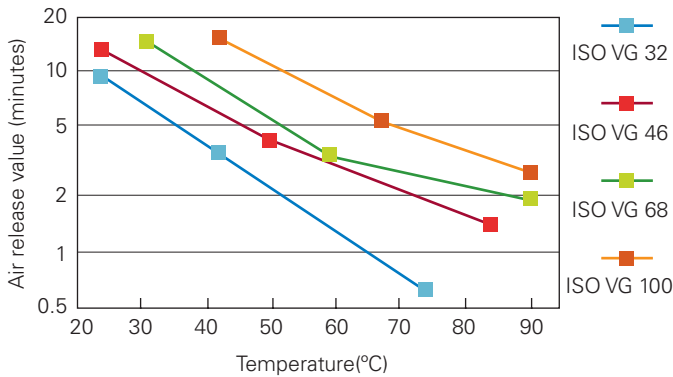
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On the other hand, high viscosity, or high resistance to flow, can result in sluggish operation, along with decreased mechanical efficiency. Energy losses from high viscosity can result in elevated fluid temperature. High viscosity can cause cavitation and poor air release properties, resulting in cavitation and aeration erosion, as shown in Figure 2. In addition, lubricants may not reach areas with tight clearances, causing failures due to inadequate lubrication.



**Figure 2. High viscosity can lead to cavitation and erosion caused by a collapsing air bubble or vacuum bubble.**

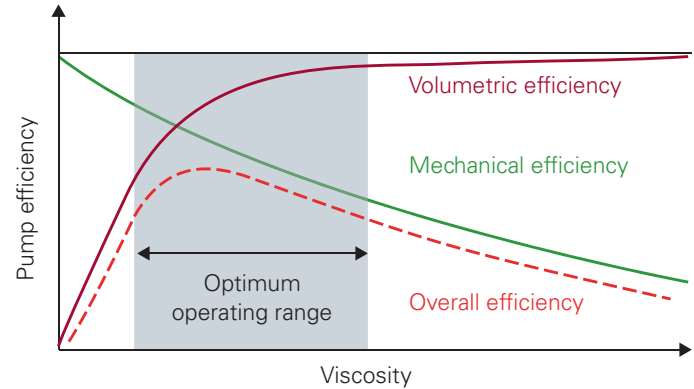
The rate of air release varies based on different viscosities and temperatures. At a given temperature, air is released faster with lower viscosity fluids, as shown in Figure 3. As the temperature increases, air is also released faster for each fluid.



**Figure 3. Air release varies based on temperature and viscosity.**

Viscosity itself is affected by temperature, with contributing factors of environment temperature, operating temperature, and system design. Suitable viscosity grade fluid needs to be selected for each application based on the operating temperatures. The fluid viscosity at operating temperature must meet the viscosity recommendations of the system components, primarily the pump. Minimum, normal, and maximum operating temperatures need to be considered for selecting the fluid viscosity grade.

Overall efficiencies of hydraulic components are related to mechanical efficiency and volumetric efficiency. Mechanical efficiency is related to frictional losses and drag due to fluid viscosity, and volumetric efficiency relates to internal leakages. Both volumetric and mechanical efficiencies depend on the viscosity of the fluid. As shown in Figure 4, volumetric efficiency increases with increased viscosity and mechanical efficiency increases with decreased viscosity. The particular range of viscosity at which overall efficiency is maximum is typically selected as the optimum range for the specific components. Viscosity recommendations should be considered for all system components, but viscosity recommendations for pumps and motors should be given prime importance.



**Figure 4. The optimum operating range of a hydraulic system depends heavily on fluid viscosity.**

Anti-wear (AW) properties of fluids are another crucial parameter to be considered. Good AW properties are required to maximize hydraulic system performance and component life. The fluid must be properly formulated and have adequate AW additives. The AW additives form a thin layer on the mating surfaces and help prevent metal-to-metal contact at boundary lubrication conditions. The resulting damages due to lack of AW properties is depicted in Figure 5.



**Figure 5. A cam ring of a vane pump was damaged due to lack of anti-wear properties.**

Insufficient AW properties can lead to cold welding and scuffing in the boundary lubrication regime, resulting in removal of surface material. Anti-wear properties are essential for both rolling and sliding contact, but the requirement for sliding contacts is more critical, as stick-and-slip type movement can occur. Even the best machined surfaces have asperities (hills and valleys). When the asperities come in contact at heavy load, they can become joined by cold welding. If the applied force is large enough to break the welding, the object suddenly moves. This causes material removal from surfaces. High additive reserve is recommended for severe applications, to allow the surfaces to slide or roll over each other without any surface damage, as shown in Figure 6.

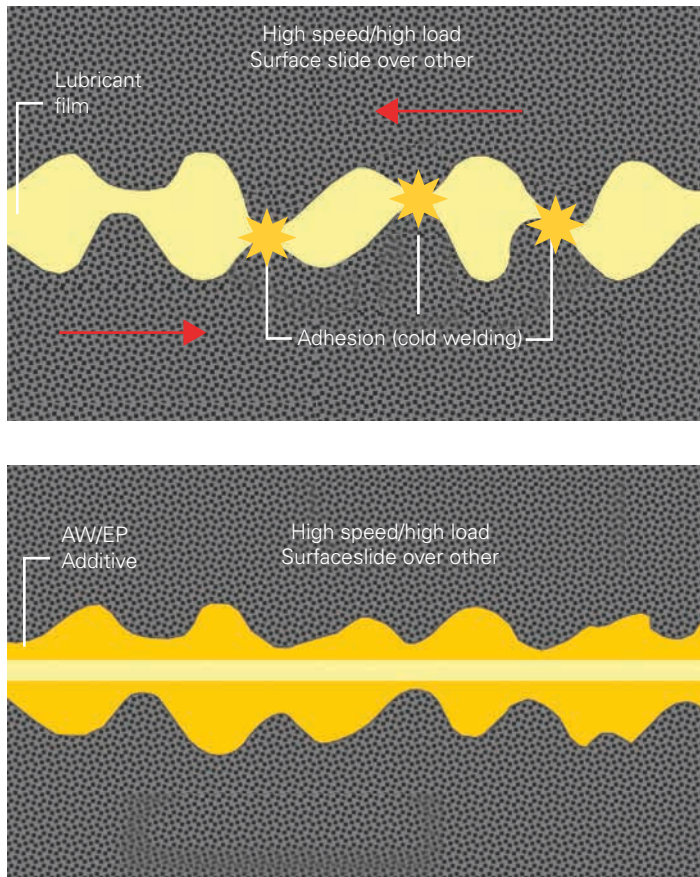


Figure 6. Anti-wear additives can help surfaces slide over each other and avoid “stick-and-slip” movement.

The Eaton-Vickers 35VQ25 pump test was developed to demonstrate a fluid’s ability to protect components from wear, thereby confirming long-term use in various operating conditions, as shown in Figure 7. The test was adopted by the American Society for Testing and Materials (ASTM) with the designation of ASTM D6973 (Standard Test Method for Indicating Wear Characteristics of Petroleum Hydraulic Fluids in a High Pressure Constant Volume Vane Pump).



Figure 7. Eaton-Vickers 35VQ25 pump test stand made at Eaton India facility.

The 35VQ pump test can be used to evaluate anti-wear properties of hydraulic fluids. Higher performance fluids can dramatically reduce wear and extend the life of components, as represented in Figure 8.

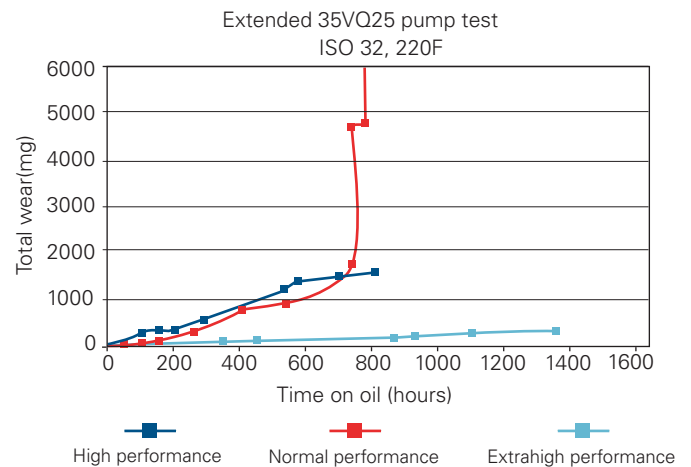


Figure 8. Results of the 35VQ25 pump test various fluids.



**Other properties to consider include:**

- **Viscosity Index (VI)** - Empirical, unit-less number indicating the effect of temperature change on the kinematic viscosity of an oil. Liquids become less viscous when heated. A high VI indicates a relatively small change of viscosity with temperature. High VI (multi-grade) fluids are recommended for applications at wide operating temperatures or at extreme environmental conditions. In general, high VI fluids are recommended for mobile applications, as they are exposed to environmental changes and high operating temperatures.
- **Shear stability** - This is the measure of a fluid's resistance to shearing. Polymers known as VI improvers are used to make high VI fluids. The molecules of VI improvers break down to smaller molecules, causing thinning of viscosity, also known as shearing. Shear stability is the most important property of a VI improver. VI improvers with low shear stability will quickly break down, resulting in thinning of oil. Viscosity after shear also needs to be considered for applications with VI improved fluids.
- **Thermal and oxidative stability** - Oxidation is chemical reaction of oxygen with oil, generating acidic byproducts. The rate of oxidation is accelerated by high temperatures, water, acids generated due to oxidation, and presence of metal catalysts such as copper. The rule of thumb is: oxidation doubles with increase of temperature by every 10°C. Oxidation will lead to increased viscosity, total acid number (TAN), generation of varnish and sludge, and darkening of fluid. The rate of oxidation can be reduced by reducing fluid temperature and using fluids formulated with quality base stocks, anti-oxidant additives, and thermally stable AW additives.
- **Hydrolytic stability** - Hydrolysis is chemical degradation of lubricants by reaction with water. Lubricant additives, especially zinc-based additives, will react with water, forming acidic by-products. The presence of metals such as copper can act as a catalyst. Ester-type base stocks also hydrolyze in presence of water. Lubricants with good hydrolytic stability will resist hydrolysis.
- **Filterability** - Fine filters used in hydraulic systems may exhibit premature filter plugging due to inappropriate formulations, water contamination, and fluid degradation. Measurement of filterability helps predict fluid behavior in filtration applications, before use in a system.
- **Demulsibility** - The ability to release water from a water-oil mixture. This characteristic is important for the equipment operating in humid climates, where the possibility of water contamination is high.
- **Rust and corrosion inhibition** - Hydraulic fluids are generally formulated with rust and corrosion inhibitors. The rust inhibitors get deposited as thin film on the metal surfaces and enable protection from rust. The corrosion additives hinder hydrolysis and prevent formation of acidic materials which causes corrosion. The ability of a fluid to prevent rust and corrosion can be measured by a rusting test using distilled water, salt water, and a steel specimen.
- **Material compatibility** - Different rubber and elastomer components, including hoses, accumulator bladders, seals, and gaskets, are used in hydraulic systems and have different compositions, or recipes. Because of these varying compositions, fluids are tested for their compatibility with most commonly used elastomers to predict the life and performance with that particular fluid.
- **Air release** - Suspended entrained air can cause many abnormalities such as poor system efficiency, system failure through erosion (similar to cavitation), and fluid degradation through micro-dieseling. Micro-dieseling occurs when air bubbles move from a low- or negative-pressure area to a high-pressure

area, get heated up due to compression, and carbonize oil at the bubble interface, resulting in carbon byproducts and oxidation. Air release characteristics have more significance in systems with relatively short residue time. An air-release test can identify the ability of a lubricant to separate entrained air.

- **Foaming tendency** - Foaming is a common problem for hydraulic systems. Large volumes of foam can cause overflow of reservoirs. Factors that lead to foaming are contamination, degraded fluid, air entrainment, and poor system design. Hydraulic fluid formulations contain foam inhibitors, but very higher dosages can give adverse effect. Foaming tendency test describes the volume of foam generated immediately after the fluid is agitated and aerated. Foam stability measures the volume of foam remaining after a specific time from the stoppage of aeration.
- **Volatility** - Volatility is the tendency of a fluid to vaporize rapidly. While generally not as critical for hydraulic fluids as for motor oils due to limited or no exposure to high temperatures and lower operating temperatures of hydraulic fluids, volatility is still a parameter to consider. Mineral base oils are mixtures of hydrocarbons of different size. At high operating temperatures, smaller molecules may escape from the oil, decreasing oil volume and increasing fluid viscosity. Improper base oil selection and blending can lead to higher volatility.

## How to Select the Right Fluid

A properly selected fluid meets the requirements of the various properties mentioned above in a balanced manner. Because identifying and interpreting all fluid requirements for a common user is difficult, Eaton has developed a full-fledged specification that cover requirements of hydraulic fluids and stipulate base stock requirements, physical properties, and performance requirements for both conventional and zinc-free hydraulic fluids, along with material compatibility with rubber materials. Fluids meeting this specification have been considered good quality hydraulic fluids[2]. Most oil/additive manufacturers follow Eaton's specification and print the same on their catalogs and on oil containers, so that the common users can identify quality lubricants easily.

Eaton has developed fluid recommendations with for Eaton hydraulic products, such as "Hydraulic Fluid Recommendations," which provides basic guidelines for selecting hydraulic fluid. The document provides viscosity recommendations and cleanliness requirements for Eaton hydraulic products[3].

Numerous lubricants other than conventional hydraulic fluids are used in hydraulic systems, such as motor oil, automatic transmission fluids, universal tractor transmission oil (UTTO), and super tractor oil universal (STOU). Some of these are formulated with mineral/petroleum-base oils, while others are synthetic-base such as those using a polyalphaolefin (PAO) base. Most Eaton components are rated with these fluids

While hydraulic pumps are generally designed to operate with mineral-base fluids, alternative fluids are sometimes used for applications where certain special properties are essential, perhaps even more important than hydraulic system performance.

For specific applications such as environmentally friendly and fire-resistant applications, certain alternate fluids such as phosphate esters, polyol esters, polyether polyols, polyalkylene glycols, vegetable oil base fluids, water glycol, and invert emulsions, are sometimes used. For example, if fire resistance is critical, fire-resistant properties may be the most important factor. Similarly, in environmentally sensitive applications, the focus may be on biodegradability and toxicity. Other fluid types, such as food-grade fluids and military specification fluids, are sometimes used in hydraulic applications.

Each alternative fluid may have certain advantages for the specified application, but their fundamental properties, such as lubrication, coefficient of friction, pressure viscosity coefficient, vapor pressure, specific gravity, and low temperature properties, may not be equivalent to those of mineral-base lubricants. Therefore, hydraulic components, especially pumps and motors may need to be de-rated to account for these adverse factors.

**To determine whether a special or alternative fluid is warranted, ask some key questions, such as:**

- Is the hydraulic application near an ignition source or high temperature surfaces, where fluid leakage could cause a fire?
- Are fire suppression measures potentially ineffective or impractical?
- Would a fire result in unacceptable impacts or costs?
- Are there any insurance benefits to using a fire-resistant fluid?
- Does the system work in an environmentally sensitive area, such as agriculture areas or forests, or where environmental regulations are applicable?
- Does the system need to be operated near or within waterways such as rivers, canals, or oceans or water sources, such as dams and reservoirs?
- Could leakage of oil cause damage to the environment, which could be a punishable offense?
- Does the application have any non-standard requirements such as military or aerospace?

If the answer is yes to any of these questions, the system may require a special fluid.

### Impacts of Using the Wrong Fluid

What happens if an improperly matched fluid is used in a pump? The answer can vary, depending on the degree of mismatch. As noted earlier, fully formulated fluids should have balanced properties. Excessive variation in any given parameter can cause direct or indirect impacts. For example, a fluid incompatible with certain rubber materials may cause failure of gaskets and other components, as shown in Figure 9.



**Figure 9. Rubber gasket extruded due to excess elongation caused by incompatible fluid.**

A single issue can cause catastrophic failure. For example, poorly maintained systems may fail catastrophically due to one or more reasons. Contamination, along with incompatible fluids, can lead to component failures, as shown in Figure 10. Any undesirable matter in the fluid is a contaminant and could be particulate matter, water, air, or other lubricants. The Eaton document “The Systemic Approach to Contamination Control” provides more information on contamination and its control[1].



**Figure 10. Contamination, lack of lubrication, and material incompatibility contributed to the failure of this piston shoe.**

### Summary

**Key points to consider when selecting fluids include the following:**

- Select an appropriate viscosity grade to ensure that the fluid viscosity at operating temperatures meets viscosity recommendations of the components, particularly for pumps.
- Fluids must pass Eaton 35VQ25 pump test and satisfy Eaton E-FDGN-TB002-E fluid specification requirements.
- Follow Eaton’s established pump ratings for applications with alternate fluids.
- With the proper fluid selection and adequate contamination control practices, end users can achieve reliable operation of pumps for many years.
- Do not assume that a new hydraulic oil is clean; it could be contaminated.
- Transfer oil to hydraulic system reservoir only through filter carts.
- Do not mix the fluid with any other type/brand/viscosity grade fluid, as it may cause gelation, additive precipitation, miscibility, filter blockage, and viscosity change.
- Clean and flush hydraulic system including reservoir if any component fail catastrophically. The particles generated may damage other components.
- Isolate contamination-sensitive components before flushing the hydraulic system.
- Contamination limit should be maintained throughout the fluid life.
- Select filter ratings based on the system cleanliness requirements.
- Flush the system with the fresh fluid, even after cleaning the system manually.
- For changing to a different type fluid, clean the system thoroughly, and flush with the fresh fluid to avoid any contamination with the previous fluid used.

- Entrained air can cause micro-dieseling resulting high fluid temperature and rapid fluid degradation. Bleed the system properly after refilling and arrest air entrainment.
- Excessive foaming in the reservoir is a sign of aeration.
- Use desiccant breather in high humidity or marine environments to avoid water contamination
- Water absorbent filters can be used for removing small quantities of water contamination. Other water removal techniques may use, if the water contamination is substantially high.

## Resources for Assistance

With all the properties to consider, fluid selection may seem like a daunting process. For assistance, contact your Eaton representative or Eaton's lubricant specialist for pump/motor ratings with different alternate fluids. As an additional resource, the Eaton Lubricant Help Desk can offer assistance in defining fluid requirements, identifying available documentation, and other technical support.

## References

1. "The Systemic Approach to Contamination Control: A Complete Guide for Maximum System Performance," Eaton Vickers, 2002 ([http://www.eaton.in/ecm/groups/public/@pub/@eaton/@hyd/documents/content/ct\\_233707.pdf](http://www.eaton.in/ecm/groups/public/@pub/@eaton/@hyd/documents/content/ct_233707.pdf)).
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3. "Hydraulic Fluid Recommendations," (Eaton Document 03-401-2010), Eaton, 2013 ([http://www.eaton.com/ecm/groups/public/@pub/@eaton/@hyd/documents/content/pct\\_500331.pdf](http://www.eaton.com/ecm/groups/public/@pub/@eaton/@hyd/documents/content/pct_500331.pdf)).

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**Eaton**  
Hydraulics Business USA  
14615 Lone Oak Road  
Eden Prairie, MN 55344 USA  
Tel: 952-937-9800  
Fax: 952-294-7722  
[www.eaton.com/hydraulics](http://www.eaton.com/hydraulics)

**Eaton**  
Hydraulics Business Europe  
Route de la Longeraie 7  
1110 Morges  
Switzerland  
Tel: +41 (0) 21 811 4600  
Fax: +41 (0) 21 811 4601

**Eaton**  
Hydraulics Group Asia Pacific  
Eaton Building  
4<sup>th</sup> Floor, No. 3 Lane 280 Linhong Rd.  
Changning District  
Shanghai 200335  
China  
Tel: (+86 21) 5200 0099  
Fax: (+86 21) 5200 0400