

# HYDRAULIC FLUIDS:

## The pressure to perform better

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## *There's growing concern for the lubricants industry to increase the performance of hydraulic applications. But higher production costs and new technological requirements make the task more difficult than ever.*

**O**ne of the oldest methods of lubrication, hydraulics have continued to evolve because of a rise in their industrial use and advanced equipment design. Current hydraulic products are expected to be versatile, multitasking agents that endure higher pressures, temperatures and speeds, so improvements to their formulations have become necessary to meet modern operating conditions.

The simple water- or oil-based hydraulic fluids that were the standard in industrial applications for so long have given way to more sophisticated formulations developed to keep pace with advances in equipment design. Those advances, of course, are driven by concerns regarding economy, efficiency and productivity—in other words, how can industry increase output while keeping down costs? Hydraulic formulations must provide sufficient protection to extend the life of expensive equipment and prevent breakdowns that interfere with production and provide long fluid life as well. At the same time, hydraulics engineers and formulators have to stay in step with—if not ahead of—equipment engineers and designers who are continually pushing technology to satisfy industry.

In the drive to produce greater power more efficiently, the principal solutions employed by engineers include the use of smaller equipment, new alloys and multi-function components. All these changes result in higher operating temperatures, faster speeds, higher flow rates, greater pressures and smaller fluid reservoirs.

Protecting today's equipment means formulating fluids that can stand up to the kinds of stresses these changes create. Modern hydraulic science involves the same basic physics as hydraulics in the ancient times. But specialized properties are required to meet the demands of new system designs that utilize converters, turbines, stators, plates, valves, pumps and piping. As the lubricants industry grows to include increased use of multigrade fluids, biodegradables and ashless products, what has traditionally been a fairly simple area of

lubrication is increasing in complexity.

The cooperative relationships that have developed between OEMs and lubricant manufacturers are an acknowledgement of the "hand-in-glove" nature of lubrication and equipment advancement. In addition, just as hydraulics engineers have to anticipate the conditions a fluid will encounter in a new operating system, so do lubricant manufacturers have to develop formulations with properties that perform under those conditions. All these efforts have the same goal: optimize the balance between performance and cost, while maximizing the life of the machine and the oil.

### **Basic ingredients**

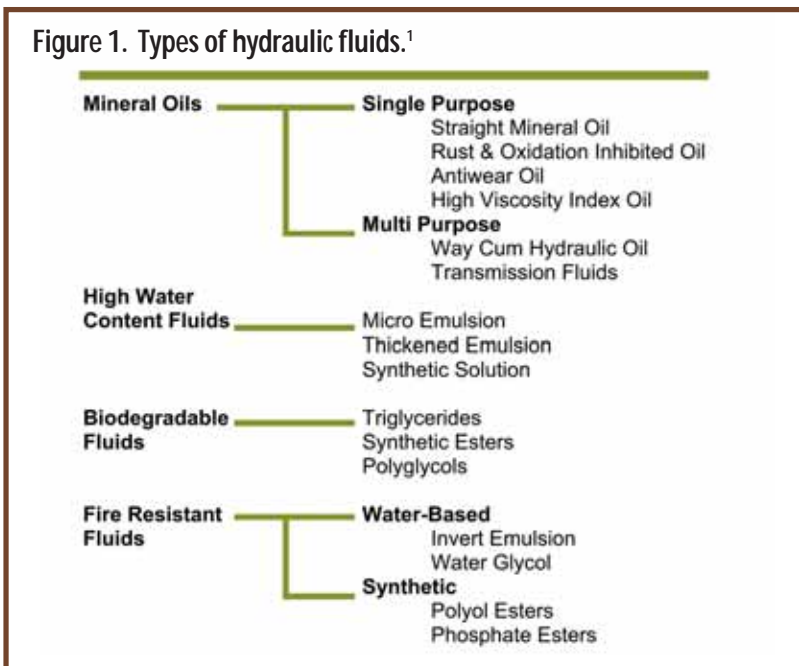
The recipe for effective hydraulic fluid performance includes three primary components:

**Base oil.** This is where it all starts. The base oil is what gives a hydraulic fluid its inherent properties such as lubricity, viscosity, oxidation stability, compressibility (bulk modulus) and equipment compatibility. The base oil also determines maintenance requirements. No base fluid can do it all, however.

**Additives.** They are chosen for selected functions to enhance the performance characteristics of the base fluid in meeting the

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Figure 1. Types of hydraulic fluids.<sup>1</sup>





specific requirements of the equipment. The balance of any single additive with other additives and with the base oil is critical; an additive that can enhance one aspect of overall performance can also negatively impact the chemistry in some other way, whether by a specific combination of ingredients or by its volume in proportion to the rest of the chemistry.

**Viscosity.** This property governs performance and reduces friction and wear, so judicious selection is required. Viscosity changes with temperature and varies per oil and formulation. How the fluid behaves over a range of temperatures is critical for most applications, so viscosity index (VI) is as important as the base oil viscosity.

Ultimately, however, none of this science functions properly unless both the correctly selected fluid and the equipment are properly maintained. Despite long-life claims for modern hydraulic fluids, no product is maintenance-free. Basic scheduled maintenance practices such as filtering and monitoring acidity, color change, viscosity and contaminants are essential to protect and preserve equipment and to gain the full performance benefits and life of the oil.

The choices for base oil have broadened as equipment technology has advanced, but the standard for many years has been mineral-based fluids.

Today's hydraulics formulators choose from a wide selection of base fluids: synthetics, biobased and fire-resistant oils, which are formulated using PAOs, diesters, polyglycols, halogenated ethers and hydrocarbons. Synthetics provide higher viscosity index, flash points and lower pour points. Often to balance cost and performance, they are blended with mineral oils for high- and low-temperature performance.

Refined mineral oils are still most widely used because additive chemistry and the science of formulating also have improved. Mineral oils also provide the best viscosity range, which makes them extremely useful across a wide range of industrial applications.

Additives are selected for their particular

Figure 2. Types of synthetic hydraulic fluids.<sup>2</sup>

Type of Synthetic	Name
Synthetic Hydrocarbons	Polyolefins
	• Polyisobutenes
	• Polyalphaolefins
	Hydrocracked Mineral Oils
Polyethers	Polyalkylene Glycols Polyphenyl Ethers
Organic Esters	Diesters
	Complex Esters
	Neopentyl Polyolesters
Phosphate Esters	Aryl Phosphates
Silicones	Polysiloxanes
	Silicate Esters
Fluorethers	Fluoroalkylether
	Perfluoropolyethers

performance characteristics and are critical when formulating for specific applications. Some hydraulic fluid manufacturers formulate their own additive chemistry, but many rely on additive suppliers to create packages that are targeted for specific applications.

Often additive chemicals are dual-function, providing protection against multiple variables. This is one reason why the balance of formulations is so critical; enhancing one chemical element may have a damaging effect on another component of the formulation.

The viscosity of a fluid is affected by pressure, temperature and shear rates, and how a fluid behaves in response to these stressors is determined primarily by the quality and characteristics of the base oil. Kinematic viscosity is closely related to friction, as the fluid must be thin enough to not produce additional resistance, thick enough to provide an adequate protection barrier and variable enough (that is, have sufficient viscosity index) that it can respond to extreme changes in temperature, pressure and load while still providing protection. Viscosity modifiers are added to fluids to increase viscosity and VI.

High VI oil has a high-performance response and can minimize leakage, which is a common problem in hydraulic equipment. Improper selection of viscosity in high-pressure systems, where leakage is a significant factor, results in a drop in viscosity and power-output reduction.

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## Current trends

Current industrial trends call for equipment with smaller reservoirs. This means hydraulic fluids are being exposed to higher temperatures, which will significantly reduce the fluid life. For every 10 C increase in operating temperature, the oxidation rate is doubled, so controlling heat generation is critical for achieving high performance and is an important factor in determining cost.

Increased operating temperatures can mean that additional heat is transferred to machine tools, which can cause materials to expand and seal elastomers to shrink and harden. This can affect the accuracy of the hydraulic equipment.

In addition, oxidized oil results in the development of corrosive acids, lacquering of critical valve surfaces, insoluble sludge formation and significant viscosity increases, which can begin to show effects by impairing the smooth functioning of the system. Continued oxidation will result in increased viscosity and foaming and decreased air-release properties. This can badly damage a machine and lead to jerkiness or inconsistent feed.

Loose metal particles such as lead, zinc, iron or copper are particularly dangerous because they effectively act as catalysts and can significantly increase oxidation. This is why most hydraulic fluids have metal passivators and soluble soaps that function as metal chelating agents and why all hydraulic media are specifically formulated with antioxidant additives that function to extend the life of the fluid.

Common antioxidants such as aryl amines, sterically hindered phenols, alkylated diphenylamines, metals passivating sulfur or phosphorous compounds or zinc dithiophosphates are always added at concentrations of 1% to 15%. The action of these oxidation inhibitors is to act as free-radical scavengers, breaking the free-radical chain reactions responsible for oxidation and the ensuing thermal degradation.

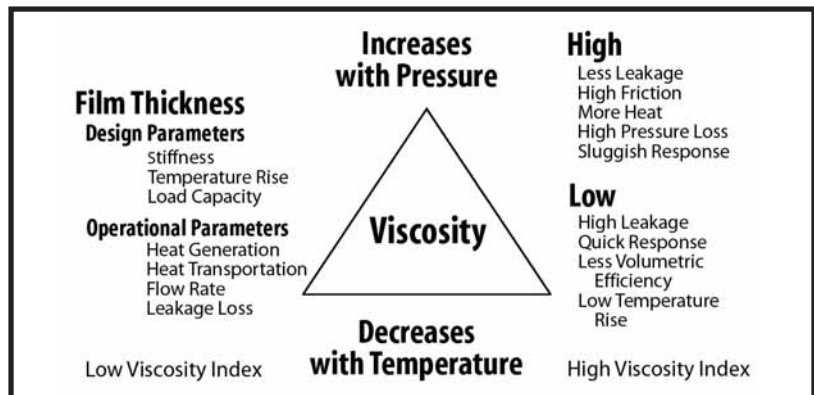
Newer hydraulic fluids are made from highly refined base oils or synthetic base fluids such as polyalphaolefins, which offer extreme high-temperature performance.

While the increased pressures in modern equipment may confer higher speeds, the result can be thickening of the lubricant. The viscosity of a hydraulic fluid can double

Figure 3. Types of additives.<sup>2</sup>

Additive	Chemical Nature	Typical % (or ppm)
Oxidation Inhibitor	Sterically Hindered Phenols Metal Dithiophosphates Sulfurized Olefins Aryl Amines	0.2-1.5
Corrosion Inhibitor	Carboxylic Acids Benzotriazole Metal Sulphonates Alkylated Carboxylic Acids	0.05-1.0
Defoamant	Polysiloxanes	
Antiwear	Organic Esters Aryl Phosphates ZDDP Organic Sulfur/Phosphorous-Compounds	2-20 ppm 0.5-2.0
Viscosity Index Improver	Polymethacrylate Esters Styrene/Isoprene Copolymers Polyolefins	3-25
Pour Point Depressant	Polymethacrylate Esters Naphthalene/Wax Condensation Products	0.05-1.5
Friction Modifier	Esters of Fatty Acids Fatty Acids	0.1-0.75
Detergents	Metal Salicylates Metal Sulphonates	0.02-0.2
Seal Swell	Organic Esters Aromatics	1-5

Figure 4. Highlights of the role of viscosity.



at high pressures, and this will affect filtration and lubrication properties. High-pressure applications, therefore, demand synthetic fluids that are less affected by pressure and higher levels of antiwear or load-carrying additives.

Higher pressures also affect the bulk modulus or compressibility of a hydraulic

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fluid. Bulk modulus is related to the stiffness of a fluid and higher pressures reduce the bulk modulus. This will affect the input/output motion of machinery and the filling and emptying modes of equipment. High operating pressures also can affect the foaming properties of the oil, thereby increasing oxidation.

But despite the desire to increase performance, there are limitations dictated by equipment components that have not advanced as quickly. According to STLE member David Wills, chief metallurgist at Sauer-Danfoss Inc., in Ames, Iowa, "Contrary to popular opinion, hydraulic system pressures, at least in our equipment, have not made any significant increases in recent years. Typically pressures have not increased because of hose limitations and limited life of purchased bearings." Naturally, with changes in those technologies, industry will seek to upgrade equipment designs that will push pressures up even further.

Another current change has been in the use of antiwear additives that are used to alleviate the scuffing wear between highly loaded sliding surfaces. These antiwear additives react with metal asperities by forming protective films that help reduce intermetallic contact and wear, allowing parts to slide with less friction and minimal metal loss. The action of the antiwear component, to a large degree, depends on the quality of the base oil. Thicker base oils have better antiwear performance because a thicker film is produced.

Many years of research have gone into

the development of antiwear formulations in order to allow them to serve this dual purpose, both antiwear and antioxidant. Zinc dithiophosphates (ZDDPs), the most common antiwear additives, also provide antioxidant protection, but ZDDPs can lead to corrosive wear at high temperatures, poor filterability and stickiness in valve movement. Such deficiencies led to the development of ashless succinimides and newer formulations that included the development of synthetic fluids, which are able to meet more severe conditions.

In fact, current trends call for the use of molybdenum dithiophosphates, which can reduce friction and wear during sliding in boundary lubrication. End-users must always remember that despite the manufacturer's efforts to provide for favorable conditions of operation within a system, the geometry of surfaces and the countless variables of temperature, pressure and speed will eventually produce some frictional force and eventual wear. The metallurgy of the contacting surfaces, temperature, lubricity of the hydraulic media and type of chemical additives will, in turn, dictate the wear the machinery experiences. Modern antiwear additives are able to deal with the thermal and frictional stresses produced in modern machinery.

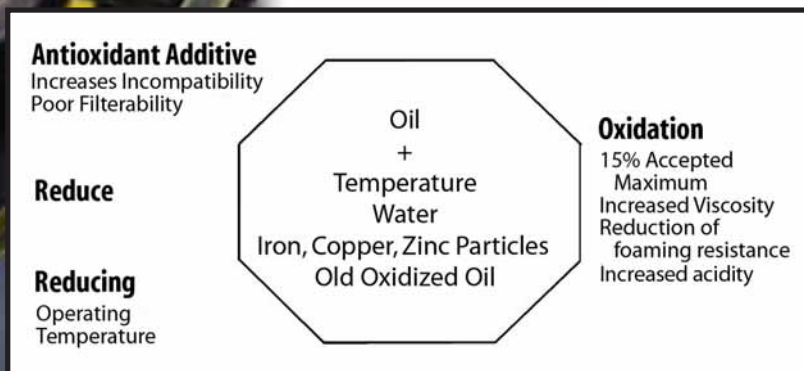
The use of smaller reservoirs, which affect thermal properties, oxidation and air-release, also has an impact on fluid foaming. This highlights the importance of using good antioxidants and antifoam additives while maintaining filterability and maintenance protocols.

Foaming will accelerate the oxidation of oil by way of air bubbles, which also can increase the temperature of the fluid. This in turn can lead to cracking and nitration of the oil and to the formation of insoluble deposits. The air-release properties of oil are directly linked to antifoam performance since air entrainment mostly escapes to the surface as foam.

High operating pressures can further aggravate the problem, which is why antifoam additives are dispersed in the oil. Common antifoam additives are liquid silicones, added at concentrations of 1 to 10 parts per million (ppm). The antifoam additive has a lower surface tension than the oil and is able to adsorb onto very thin oil

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Figure 5. Highlights of antioxidant properties.



films. These oil films are always present between air bubbles in a foam, disturbing their stability and resulting in the rupturing of the foam bubbles.

The oil surface tension can be used to determine the depletion of antifoam additives. A low-viscosity oil has a higher surface tension, resulting in reduced foaming. Persistent foaming should be investigated, as it could indicate contamination from grease, water and other particulates. Oil should be kept clean in order to reduce or avoid foaming. Vent valves should always be checked to further reduce air entrapment.

Other causes of persistent foaming include a high rate of oil circulation and the fluid's time in service.

End-users must remember to monitor a high-pressure system and its foaming and air-release properties in order to avoid losses in efficiency, spongy control, noisy operation, pressure spikes, temperature increases, accelerated oxidation and cavitation.

High-pressure systems lead to fast pressure cycles and air entrainment, which can lead to air locking and pump whining. Factors that dictate the air entrainment and air-release properties include viscosity, pressure, contaminants and additives. Air-release time increases with higher viscosity and with highly contaminated oil, while low temperatures in a reservoir result in a reduced rate of bubble collapse. High temperatures also promote bubble formation; leaking joints or equipment, low oil levels and high pump speeds are common sources of air entrainment.

### Maintenance

Regardless of the product, a good maintenance program is critical to optimizing performance. Many manufacturers recommend that users filter the oil initially to prevent impurities in the new oil from catalyzing and degrading in use. STLE member Michael Roe, products technical advisor at ExxonMobil Lubricants & Specialties in Houston, says, "Both initial oil cleanliness and keeping the oil clean during service are extremely important. There are various esti-

mates out there, but particulates and debris can cause up to 80% of hydraulic failures. It is important to filter the oil to the cleanliness level required by the equipment and application, typically at the point of use."

Good maintenance practices are those that routinely check for water and air contamination; equipment must be maintained in order to prevent these threats to good operation and long equipment life, and a regular maintenance schedule allows early detection of problems so they can be remedied immediately.

Roe explains, "It is paramount to make sure that equipment owners can both accurately measure the cleanliness of the oil and that they have the proper filtration to meet cleanliness targets. Not only does particle contamination reduce oil quality and life, it also reduces component life, equipment uptime and productivity, thereby increasing operation costs."

Equipment owners need to talk to their OEMs and be well informed about requirements. Building a relationship with oil or additive suppliers is crucial for equipment longevity and optimum performance.

Wills says, "If I could send one message to end-users it would be to recommend that they purchase the best fluid available, even if that means having to spend a little more than they would like. Going cheap on fluids results in costly failures that could have been prevented. Our recommendation is to select the best premium grade antiwear fluids available. Certainly there are times when fire-resistant fluids or environmentally friendly fluids must be used, but many of these fluids now have excellent performance. The next recommendation—a close second if not first—is to keep your system clean with filters and scheduled maintenance. This is probably the biggest issue in hydraulic system failures—contaminated fluids resulting in abrasive wear, adhesive wear, plugged control systems and other problems."

### Trends

A growing trend among additive manufacturers is to further develop the shear stability of multigrades. In fact, competing products have been on the market for some time.

According to Karen Bonev of The Lubrizol Corp., in Wickliffe, Ohio, "Pump manufacturers are changing their attitude toward

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multigrade hydraulic fluids. They were once worried these products wouldn't provide shear stability. We now have products that have improved the shear stability of multigrades to maintain viscosity requirements. This should be a growing market."

Bonev says that even though there has traditionally been resistance in the market to the widespread use of multigrades, these fluids can meet more stringent equipment requirements by providing better oxidation resistance, better antifoam characteristics, improved air-release properties, improved thermal stability, extended antirust performance, increased extreme pressure and antiwear performance and better filtration.

Bonev also notices that industry is showing its acceptance of multigrade fluids because they have seen results. "The use of multigrade fluids is a growing market because more shear stable polymers give us a line of very shear stable products that help maintain viscosity requirements in extreme applications. When customers see that it works, they are well satisfied," she says.

Environmental concerns are driving the industry toward non-zinc or ashless products. Taking the zinc out of a fluid eliminates the heavy metal content, but zinc is critical to antiwear and antioxidant performance. Removing zinc usually compromises performance in those areas. Bonev does not see an easy or fast solution to this particular problem, even with the focus on environmentalism. She says, "In fact, zinc antiwear hydraulics work so well and are so cost-efficient that it probably will be difficult to replace them for some time."

Biodegradable fluids are often formulated using ashless chemistry. Bonev says, "Initially there were performance tradeoffs in the formulation of biodegradable products. Fluids made from vegetable oil suffered from oxidation problems. We now use ester to form biodegradable products, and performance has improved significantly."

In the near future, nanotribology will play a bigger role in high-temperature hydraulic fluids. These new generation additives will meet the challenges of friction and wear at the atomic-scale. Newer additives will have better adherence to surfaces, providing a friction barrier that helps reduce temperature increases and mechanical vibrations, thereby reducing noise caused by sliding

elements and cavitation from metal-to-metal contact.

Wills says, "The major challenges we face with respect to tribology in designing new components are related to preventing the onset of adhesive wear (scuffing). Surface finish, roundness of parts, dimensional clearances and material pairs are all factors related to preventing adhesive wear."

However, nanotribology formulations will provide films that are mechanically as well as chemically resistant, such that they can withstand the most extreme conditions, including shearing off or melting. This will totally alter the face of equipment design by significantly reducing adhesive wear and the ensuing machine wear.

Another advance that could emerge from nanotribology is superlubricity. This is the characteristic seen in the behavior of graphite, the molecules in the layers of lubrication are so shear stable that they are able to move against each other without breaking while clinging to the metal surface. This atomic-scale behavior minimizes friction to a degree that is as close as we have seen in a practical application to zero friction. This leads to the possibility of a hydraulic medium that provides low wear, protection from rising temperatures, reduced friction and significant noise reduction.

Hydraulic fluids, which have been in use since engineering and fluid mechanics were discovered, have undergone serious changes in formulation. The hydraulic fluids of today are radically different than the hydraulic fluids of ancient times because the technical requirements placed on hydraulics continue to increase.

This is why fluid and equipment manufacturers will continue to work together to advance hydraulic fluid technology to meet the evolving challenges of today to those of tomorrow. <<

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