Hydraulic fluids

Hydraulic fluid can be the most vital component of a hydraulic system, so you must carefully consider dozens of characteristics before making a final selection.

The demands placed on hydraulic systems constantly change as industry requires greater efficiency and speed at higher operating temperatures and pressures. Selecting the best hydraulic fluid requires a basic understanding of each particular fluid's characteristics in comparison with an ideal fluid. An ideal fluid would have these characteristics:

- thermal stability
- hydrolytic stability
- low chemical corrosiveness
- high anti-wear characteristics
- low tendency to cavitate
- long life
- total water rejection
- constant viscosity, regardless of temperature, and
- low cost.

Although no single fluid has all of these ideal characteristics, it is possible to select one that is the best compromise for a particular hydraulic system. This selection requires knowledge of the system in which a hydraulic fluid will be used. The designer should know such basic characteristics of the system as:

- maximum and minimum operating and ambient temperatures
- type of pump or pumps used
- operating pressures
- operating cycle
- loads encountered by various components, and
- type of control and power valves

Influential factors

Each of the following factors influences hydraulic fluid performance:

Viscosity — Maximum and minimum operating temperatures, along with the system's load, determine the fluid's viscosity requirements. The fluid must maintain a minimum viscosity at the highest operating temperature. However, the hydraulic fluid must not be so viscous at low temperature that it cannot be pumped.

Wear — Of all hydraulic system problems, wear is most frequently misunderstood because wear and friction usually are considered together. Friction should be considered apart from wear.

Wear is the unavoidable result of *metal-to-metal* contact. The designer's goal is to minimize metal breakdown through an additive that protects the metal. By comparison, friction is reduced by *preventing* metal-to-metal contact through the use of fluids that create a thin protective oil or additive film between moving metal parts.

Note that excessive wear may not be the fault of the fluid. It may be caused by poor system design, such as excessive pressure or inadequate cooling.

Anti-wear — The compound most frequently added to hydraulic fluid to reduce wear is zinc dithiophosphate (ZDP), but today, ashless anti-wear hydraulic fluids have become popular with some companies and in certain states to reduce loads on waste treatment plants. No ZDP or other type heavy metals have been used in the formulation of ashless anti-wear fluids.

The pump is the critical dynamic element in any hydraulic system, and each pump type (vane, gear, piston) has different requirements for wear protection. Vane and gear pumps need antiwear protection. With piston pumps, rust and oxidation (R & O) protection is more important. This is because gear and vane pumps operate with inherent metal-to-metal contact, while pistons ride on an oil film.

When two or more types of pumps are used in the same system, it is impractical to have a separate fluid for each, even though their operating requirements differ. The common fluid selected, therefore, must bridge the operating requirements of all pump types.

Foaming — When foam is carried by a fluid, it degrades system performance and therefore should be eliminated. Foam usually can be prevented by eliminating air leaks within the system. However, two general types of foam still occur frequently:

- surface foam, which usually collects on the fluid surface in a reservoir, and
- entrained air.

Surface foam is the easiest to eliminate, with defoaming additives or by proper sump design so that foam enters the sump and has time to dissipate.

Entrained air can cause more serious problems because this foam is drawn into the system. In worst cases, it causes cavitation, a hammering action that can destroy parts. Entrained air is usually prevented by properly selecting the additive and base oils. Caution: certain anti-foam agents, when used at a high concentration to reduce surface foam, will increase entrained air.

Also linked to the foam problem, is fluid viscosity, which determines how easily air bubbles can migrate through the fluid and escape.

R & O — Most fluids need rust and oxidation inhibitors. These additives both protect the metal and contain anti-oxidation chemicals that help prolong fluid life.

Corrosion — Two potential corrosion problems must be considered: *system rusting* and *acidic chemical corrosion*. System rusting occurs when water carried by the fluid attacks ferrous metal parts. Most hydraulic fluids contain rust inhibitors to protect against system rusting. The tests used to measure this capability are ASTM D 665 A and B. To protect against chemical corrosion, other additives must be considered. The additives must also exhibit good stability in the presence of water (hydrolytic stability) to prevent break down and acidic attack on system metals.

Oxidation and thermal stability — Over time, fluids oxidize and form acids, sludge, and varnish. Acids can attack system parts, particularly soft metals. Extended high-temperature operation and thermal cycling also encourage the formation of fluid decomposition products. The system should be designed to minimize these thermal problems, and the fluid should have additives that exhibit good thermal stability, inhibit oxidation, and neutralize acids as they form.

Although not always practical or easy to attain, constant moderate temperature and steady-state operation are best for system and fluid life.

Water retention — Large quantities of water in a hydraulic fluid system can be removed by draining the sump periodically. However, small amounts of water can become entrained, particularly if the sump is small. Usually, demulsifiers are added to the fluid to speed the separation of water. Filters can then physically remove any remaining water from the hydraulic fluid. The water should leave the fluid without taking fluid or additives with it.

Temperature — System operating temperature varies with job requirements. Here are a few general rules: the maximum recommended operating temperature usually is 150° F. Operating temperatures of 180° to 200°F are practical, but the fluid will have to be changed two to three times as often. Systems can operate at temperatures as high as 250° F, but the penalty is fairly rapid decomposition of the fluid and especially rapid decomposition of the additives — sometimes within 24 hours!

Fluid makeup

Most fluids are evaluated based on their ratings for rust and oxidation (R & O), thermal stability, and wear protection, plus other characteristics that must be considered for efficient operation:

Seal compatibility — In most systems, seals are selected so that when they encounter the fluid they will not change size or they will expand only slightly, thus ensuring tight fits. The fluid selected should be checked to be sure that the fluid and seal materials are compatible, so the fluid will not interfere with proper seal operation.

Fluid life, disposability — There are two other important considerations that do not directly relate to fluid performance in the hydraulic system, but have a great influence on total cost. They are *fluid life* and *disposability*.

Fluids that have long operating lives bring added savings through reduced maintenance and replacement-fluid costs. The cost of changing a fluid can be substantial in a large system. Part life should also be longer with the higher-quality, longer-lived fluid.

Longer fluid life also reduces disposal problems. With greater demands to keep the environment clean, and ever-changing definitions of what is toxic, the problem of fluid disposability increases. Fluids and local anti-pollution laws should both be evaluated to determine any potential problems.

Synthesized hydrocarbon (synthetic) hydraulic fluids contain no waxes that congeal at low temperatures nor compounds that readily oxidize at high temperatures which are inevitable in natural mineral oils. Synthetic hydraulic fluids are being used for applications with very low, very high, or a very wide range of temperatures.

Fire-resistant fluids

The overwhelming majority of hydraulic components and systems are designed to use oil-based hydraulic fluids. No wonder; these fluids rarely present significant operating, safety, or maintenance problems. Unfortunately, there are circumstances where using oil-based fluid should be avoided. One common fluid power application is in an environment with potential ignition sources — an open flame, sparks, or hot metal. In these environments, a leak spraying from a high-pressure hydraulic system could cause a serious fire and result in major property damage, personnel injury, or even death.

Even though most oil-based hydraulic fluids have relatively high flash/fire points (>300° F), small leaks in a high-pressure system can produce a finely atomized spray that can travel significant distances. If an ignition source is encountered, complete ignition of the spray envelope can occur. The alternative is to use a hydraulic fluid that eliminates or significantly reduces this hazard: any of several fire-resistant hydraulic fluids (FRHFs).

How far we've come

Apart from isolated segments of basic research, little progress was made in developing suitable FRHFs until the end of World War II. During the war, tragic incidents related to hydraulic fluid fires and major property losses at steel mills and foundries graphically illustrated the urgent need for something to be done. Similar incidents in captive environments such as coal mines during the rapid post-war industrial expansion helped motivate a major joint research effort between government and industry. This work was directed at developing fluids that could replace oil-based hydraulic fluids at a reasonable cost and with no significant reduction in hydraulic system performance. Two basic approaches were undertaken. One involved the introduction of water into the fluid to act as a "snuffer" if the fluid ignited. The other involved synthetic, non-aqueous products whose chemistry resisted burning or generated products of combustion that helped extinguish any flame.

Commercial products in both categories evolved during the 1950s and '60s and are still in use today. In the early 1970s, an additional synthetic type of fluid was introduced to address many of the drawbacks inherent in the earlier types. Since the introduction of each type, many improvements have been made in fire resistance, anti-wear properties, and overall quality.

Where we are

Water glycol and **invert emulsion** constitute the major fluid types of water-containing products. Water glycol is a true solution of a glycol (such as ethylene glycol) in water, along with a variety of additives to impart viscosity, corrosion protection, and anti-wear properties. A shear-stable thickener, which has improved over the years, represents the novel technology aspect of the fluid. Water glycol contains approximately 40% water. Despite a number of drawbacks, water glycol is the dominant FRHF on the market today and is used in a wide variety of applications.

An invert emulsion also contains approximately 40% water but is a stable emulsion of water dispersed in oil. The outer phase, oil, represents the wetting surface; the inner phase, water, provides the fire retardant-element. Oil-soluble additives provide anti-wear properties, corrosion protection, and emulsion stability. Inverts, at one time, were commonly used but are losing favor in industry today.

Synthetic fluids initially were represented by a class of chemical compounds known as **phosphate esters**, which are reaction products between phosphoric acid and aromatic ring-structure alcohols. These fluids are extremely fire resistant and have widespread industrial use, as well as military and aircraft service. However, their popularity has declined because of environmental, cost, and compatibility factors.

The other type of synthetic fluids in use are synthetic hydrocarbons, more specifically, **polyol esters**. These fluids are the reaction products between long-chain fatty acids (derived from animal and vegetable fats) and synthesized organic alcohols. These products contain additives to impart anti-wear properties, corrosion protection, and viscosity modification. Fire resistance results from a combination of high thermal properties and physical characteristics. This is the most recent category of FRHFs and has gained widespread and growing use.

What is fire resistance?

The term "fire resistant" often is misunderstood or interpreted to be overly inclusive; it seems appropriate to standardize the terminology and review the accepted test methods for judging the fire resistance of a given fluid. First, there is no single property or test of a fluid, such as flash/fire point, auto ignition temperature (AIT), etc. that will quantitatively rate its relative fire resistance. This has led to a "simulated incident" approach in which tests are designed to replicate a worst-case scenario in typical applications where fluid power is used near a potential fire hazard. Fluids generally pass or fail these tests, and those that pass are incorporated into an Approval Guide or List of Qualified Fluids.

In the United States, two test protocols have evolved and are generally regarded as benchmarks in the industry. One was developed by Factory Mutual Research Corporation (FMRC). Their original intent was to use the test results in the risk-assessment programs of those insurance companies under the Factory Mutual System umbrella. The test has since become the chief qualification for commercial companies using FRHFs; all fluid suppliers submit products seeking "FMRC Approval." The FMRC Approval Guide lists over 300 FRHFs from approximately 50 suppliers. Factory Mutual's program is now global in scope.

FMRC addresses the definition of FRHF in the following excerpt in their introduction to the hydraulic fluids sections of their Approval Guide:

Less flammable hydraulic fluids approved and listed here have been tested to evaluate fire hazard only. All presently available fluids will burn under certain conditions. In each case the fire hazard has been reduced to an acceptable degree, meeting the Approval Standards of FMRC; other fluid properties are not investigated.

This paragraph accurately puts the intent of FRHFs into the proper perspective. They are not fireproof but, rather, they significantly reduce the potential hazard associated with oil-based products. In the FMRC tests, the fluid is conditioned to 140°F, pressurized to 1000 psi in a steel cylinder, and discharged through an oil burner-type nozzle. The spray generated is intended to simulate a high-pressure hydraulic system leak. A gas flame is passed through (not retained in) the spray envelope at two distances downstream of the nozzle. There may be local burning at the point of flame entry, and the pass criteria dictate that any flame must self-extinguish when the ignition source is removed; no flame may propagate back to the nozzle. This process is repeated 20 times, and the burn duration timed. Any burn duration over 5 sec is considered a fail.

A second test uses the same spray directed at an inclined metal channel heated to 1300°F. In this test, the spray is continuous for 60 sec. The criteria are:

1. The spray in contact with the channel may not burn, or

2 If spray ignition takes place, fluid rolling off the channel cannot continue to burn, and the flame cannot follow the spray if directed away from the channel.

If these conditions are satisfied, the fluid is approved. Statistics are not available, but many products in all of the fluid categories described do not pass this test.

The Mine Safety & Health Administration (MSHA) has had in place for many years an evaluation program for qualifying fluids that are used underground, primarily in coal mines. MSHA testing is similar to FMRC's in the sense that a spray mist of the candidate fluid is generated. However, the ignition mechanism is somewhat different in the MSHA test. Under this procedure, a spray mist is directed continuously at a variety of ignition sources that include an open gas flame, a welding arc, and burning rags. The pass criteria are that localized burning in the spray mist extinguish within 5 sec, and there can be no sustained propagation along the spray axis. They also have an AIT criterion and a wick test to assess the rate of evaporation of water from a candidate product. MSHA tests also have a relatively high rate of product rejections.

Since both of these tests involve fluids submitted by the supplier to the testing agency, both FMRC and MSHA have comprehensive manufacturer auditing programs in which quality-assurance programs are carefully evaluated and monitored by periodic, on-site inspections. This may include retests of approved fluids.

Other tests

In addition to these "third party" ratings of FRHFs, many companies have developed their own fire-resistance tests that must be considered in addition to a product having FMRC approval. Again, these tests generally follow the simulated incident philosophy and are specific to the type of industry involved. Examples of these include exposing the candidate fluid — in spray or non-spray form — to a hot manifold, molten metal, heated blocks of a representative metal, burning rags, hot sand, etc. The evaluation criteria may be no burning, limited burning, no smoke, non-propagation, etc. Minimum AIT and flash/fire point temperatures also are used either independently or in combination with a test described above.

In all of these tests, a product is either approved or rejected; there is no ranking or rating of approved products. This aspect, the occasional lack of reproducibility, and the absence of service history of a fluid has led FMRC to develop a new test that will quantify the relative fire resistance of various fluids. The test procedure involves measuring the heat release of a fluid under a fixed-burn condition and combining this value with a separately determined measurement of the energy required to initiate burning. These values are used to establish a Spray Flammability Parameter for each product evaluated. This test and a new approval standard currently are under review by FMRC and have not been formally adopted.

Other concerns

The major problem facing a designer converting a hydraulic system from an oil-based fluid to FRHF is selecting the particular type that will minimize the cost of conversion and maximize the operating and safety benefits. The choice becomes a trade-off of characteristics associated with each type. Each product group offers advantages and disadvantages for any given application. It is beyond the scope of this article to attempt to make recommendations for certain end-users, but the major attributes and shortfalls of the various fluid types can be addressed.

The table on pages 38 and 39 summarizes these characteristics, price ranges, and some of the considerations associated with converting a system containing oil-based fluid to a FRHF. Many suppliers offer products for each type of FRHF, which may vary considerably in price, quality, and after-sale service.

Where we're going

Significant improvements continue to be made with both water glycol and polyol ester fluids, and this trend should continue. Moreover, the impact of more-stringent environmental regulations will be more strongly felt in the next few years and may even restrict the choice.

The motivation for converting from an oil-based fluid will also strengthen as waste control regulations expand for any product containing oil. In some areas, "hydraulic oil" already is considered a hazardous material. As their prices decrease, fluids having the capability of being non-toxic and readily biodegradable will further expand the motivation to replace oil-based hydraulic fluids.

Environmental fluids

In some cases, environmental considerations necessitate the selection of a zinc-free ashless petroleum or a biodegradable hydraulic fluid.

The Environmental Protection Agency (EPA) continues to advocate the use of environmentally safe hydraulic fluids in place of conventional petroleum-based hydraulic oils — particularly in applications where fluid leakage could have a negative impact on the environment. Spills of standard, petroleum-based hydraulic fluids are known to kill marine life and contaminate soil. Environmentally safe hydraulic fluids are formulated to avoid those undesirable results.

To be classified as environmentally safe, a fluid must be readily biodegradable (more than 60% of the fluid must break down into innocuous products when exposed to the atmosphere over a 28-day period) and virtually non-toxic (more than half the rainbow trout fingerlings in a population must survive after four days in an aquatic solution with concentrations of the fluid greater than 1000 ppm). The major benefits of these fluids: small spills are readily biodegradable which reduces the cost of clean-ups; and the fluid is unlikely to harm plant life, fish, animals, and humans who come in contact with it.

Hydraulic applications that could be considered environmentally sensitive include mobile equipment in general, with emphasis on forestry and construction machinery, and marine equipment used on fishing boats, off-shore drilling operations, and hydraulically operated bridges, locks, and dams. Other locations are commercial elevators and equipment in amusement parks.

Three base oils

Three different base oils have been tried as environmentally safe hydraulic fluids. They are synthetic esters, polyglycols, and vegetable oils. Synthetic esters can be formulated as biodegradable fluids with superior lubrication performance, but their high cost has limited their usage. Polyglycols — attractive because they are less expensive than synthetic esters — have been used more commonly. However, polyglycols lack required biodegradability and are potentially toxic in water when mixed with lubricating additives. Vegetable oils, such as rapeseed oil, have excellent natural biodegradability, are in plentiful supply, and are inexpensive. They have become the most commonly used environmentally safe fluids in hydraulic systems.

The base fluids of biodegradable hydraulic fluids are usually vegetable oils, selected synthetic esters, or a blend of the two. Biodegradable hydraulic fluids typically contain low toxic, ashless inhibitors and additives to enhance performance. Properly formulated biodegradable hydraulic fluids can provide effective wear resistance similar to petroleum anti-wear hydraulic fluids. However, the biodegradable fluids may be susceptible to water contamination and may exhibit poor oxidative stability, especially when the base fluids are vegetable oils. The use of a synthetic-ester base usually improves the water tolerance and oxidation resistance of the fluids.

The tradeoff between environmental advantages and potential performance deficiencies of biodegradable hydraulic fluids suggests that these fluids are most suitable for applications in environmentally sensitive areas, and that they are not meant as a direct replacement for petroleum hydraulic fluids. Their use should be considered in outdoor equipment, such as in timber harvesting, agricultural equipment, airport service fleets, construction machinery, recreational resorts, or wherever contamination of ground or water by petroleum lubricants could be a problem. Vegetable oil-based fluids may be considered when operating temperatures range from 0° to 180° F. For operations in sub-zero temperatures or temperatures higher than 180° F, synthetic ester-based fluids are preferred.

Additives

Like petroleum oils, vegetable oils or synthetic esters rely on specially selected additives to improve their performance as lubricants. The additives contained in biodegradable hydraulic fluids typically exhibit very low toxicity. Unlike petroleum oils, vegetable oils contain unsaturated hydrocarbons and are natural occurring esters. The unsaturation leads to rapid oxidation at elevated temperatures and poor low temperature flow properties. This low-temperature fluidity can be improved by additives, but their oxidation stability remains a performance concern.

International guidelines

Throughout Europe, the development of guidelines for biodegradable lubricants is typically left to local authorities or non-government organizations. In Germany, *Blue Angel* labels will be awarded to biodegradable hydraulic fluids. The Blue Angel for biodegradable hydraulic fluids will likely require that the base fluids must be readily biodegradable — greater than 80% biodegradation in 21 days by CEC L-33-A93 Test, or greater than 70% biodegradation in 28 days by the Modified Sturm Test. In addition, all components must be Water Hazard Class 0 or 1, which means the components are not water pollutants.

Environmental Choice Program of Canada is currently in the process of reviewing a guideline on biodegradable, non-toxic hydraulic fluids. It will likely include a requirement that base fluids exhibit greater than 90% biodegradation in 21 days by CEC L-33-A93.

In the United States, ASTM D-2.N.3 on eco-evaluated hydraulic fluids has drafted an information guide that addresses the means of assessing the biodegradability of hydraulic fluids. D-2.N.3 is currently developing environmental classifications for hydraulic fluids. A In December 1995, ASTM D-2.12 on Environmental Standards for Lubricants completed a standard test especially designed to determine the aerobic aquatic biodegradability of all lubricants and their components. The test is similar to the Modified Sturm Test, which measures the evolution of carbon dioxide in 28 days. This standard is being published as ASTM D 5864. ASTM D-2.12 is currently developing other environmental standard tests for lubricants, which include an aquatic toxicity test for fish and large invertebrates; a manometric respirometry biodegradation test method; and a Gladhill Shake Flask biodegradation test.

Initially designed to measure the biodegradability of 2-cycle engine oils, CEC L-33-A93 has been the most widely applied biodegradation test for lubricants in Europe since the early 1980s. The test uses infrared spectroscopy to measure the disappearance of certain hydrocarbons over a 21-day period when the lubricant is mixed with an inoculum containing micro-organisms. Thus, the CEC test is a only a measure of primary biodegradation.

Unlike the CEC test, the Modified Sturm Test is a measure of ultimate biodegradation. By measuring the production of CO_2 over 28 days, the test estimates the extent to which the carbon in a lubricant is converted by micro-organisms to the elements found in nature — namely: CO_2, water, inorganic compounds, and biotic mass. Because this test was designed originally for water-soluble, pure compounds, it is difficult to use for testing lubricants, most of which are water-insoluble, complex mixtures.

The new ASTM D 5864 test is similar to the Modified Sturm Test. It is specially designed for testing water insoluble complex lubricants.

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Environmentally safe and fire-proof

A drawback of most hydraulic fluids, including some fire-resistant fluids, is their toxicity — either to personnel, the environment, or both. Furthermore, they are only fire *resistant*, and most will burn under certain conditions. Recently introduced synthetic water additives, on the other hand, mix with water (usually in a concentration of 5%) to become fire *proof*; the solution actually could extinguish a fire.

These water-based fluids, in general, also offer a cost advantage over most other fluids because one gallon of concentrate produces 20 gallons of hydraulic fluid. When disposal expenses enter calculations, the cost differential becomes even greater — especially with a solution containing non-toxic, readily biodegradable synthetic water additives that require no treatment. The accompanying table summarizes characteristics of common fire-resistant and fire-proof fluids.

There are, however, important performance and operating characteristics of water-based fluids that cannot be ignored. First, water-based fluids in general have much lower viscosity, film strength, and lubricating qualities than oil-based fluids. This means that system components — especially pumps, valves, and actuators — must be designed specifically for operation with water-based fluid. You can't just drain fluid from a system containing oil-based fluid and expect it to run on water-based fluid.

A perception remains today that components for water-based fluid are much more expensive and larger — especially valves — than their conventional counterparts. While this may have been true 20 years ago, the cost premium for valves and other components designed for water-based fluid has narrowed to about 30%. This investment can easily be recovered in the cost of fluid alone, not to mention disposal and treatment costs. Moreover, valve size has been reduced dramatically: many are available with standard NFPA footprints.

Next, any potential for freezing must be considered. Traditionally, ethylene glycol is added to water to lower the solution's freezing point. However, using highly toxic ethylene glycol in a solution containing the synthetic additive would completely negate the purpose of using an environmentally safe additive. Using *propylene* glycol instead as antifreeze maintains the environmental integrity of the solution because propylene glycol is so non-toxic that it is approved for use in food by the U. S. Food & Drug Administration.

Finally, because the fluid is nontoxic, it naturally tends to support microbial growth. To minimize or prevent consequences associated with this problem, judicious use of bacteriostatic additives and effective sealing and reservoir design should be practiced.

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The readily biodegradable question

One question that often comes up is whether a fluid is *readily biodegradable* or just *biodegradable*. Most things are biodegradable, given enough time and proper conditions. Readily biodegradable means that a substance exhibits a result equal to or greater than a pre-set requirement in a standard test.

For example, XYZ Standard requires 80% or higher biodegradation by CEC L-33-A93 in 21 days. If a lubricant meets this requirement, it is considered readily biodegradable by the XYZ Standard. Ideally, any claim that a lubricant is readily biodegradable also also specify the test and standard.

Vegetable oils or synthetic esters?

Being natural occurring esters, vegetable oils are susceptible to hydrolysis, which leads to fluid decomposition and degradation, especially in the presence of heat. Because of their polarity, vegetable oils tend to cause elastomers to swell, though in most cases the degree of swell is insufficient to cause any serious concern in hydraulic applications.

On the other hand, vegetable oils offer excellent lubricity, intrinsic high viscosity index, and good anti-wear and extreme-pressure properties. Well-formulated, biodegradable hydraulic fluids based on vegetable oils can easily pass the demanding Vickers 35VQ25 or Denison T5D-42 vane-pump wear tests. They also can meet the requirements of major OEMs for premium hydraulic fluids, except hydrolytic, thermal, and oxidation stability. Experience has shown that vegetable oil-based biodegradable hydraulic fluids can perform satisfactory for years under mild climate and operation conditions (temperatures below 160° F, and hydraulic systems kept free of water contamination).

The use of synthetic esters — typically polyol esters — provides better hydrolytic, thermal, and oxidative stability, and excellent low-temperature fluidity, while preserving the high biodegradability and low toxicity of the fluids. For nearly 30 years, polyol esters have been used to formulate aviation gas turbine lubricants, which demand high thermal and oxidation stability at extreme temperatures. While a vegetable oil-based hydraulic fluid can perform between 0° to 180° F, a similar fluid based on synthetic esters can be used between –25° and 200° F. Similar to vegetable oils, synthetic esters have the tendency to swell and soften elastomers, although again, the swell should not be a concern for most hydraulic applications.

Fluid handling

Vegetable oil or synthetic ester-based biodegradable hydraulic fluids are fully miscible with each other and with petroleum hydraulic fluids.

However, when a biodegradable hydraulic fluid is mixed with petroleum lubricants, its biodegradability typically decreases, and its toxicity increases. Because of their susceptibility to hydrolysis, vegetable oil- or synthetic ester-based fluids should be kept free of water contamination, both in storage and in everyday use.

There is no regulation permitting shortcuts in the disposal of biodegradable hydraulic fluids. Such disposal should be handled in the same manner as the disposal of petroleum fluids, in accordance with applicable federal, state, and local laws and regulations.

The future of biodegradable fluids

Government regulations and codes, and the environmental awareness of lubricant users are the driving forces for the growing use of biodegradable hydraulic fluids. However, the lack of definition and standards for biodegradable fluids in the United States impedes the market development for these fluids. Development of new standards and guidelines by ASTM and other industrial and governmental organizations will inevitably influence the growth of biodegradable fluids.

Meanwhile, lubricant suppliers continue to develop and evaluate new additive chemistries that provide greater oxidative, thermal, and hydrolytic stability properties for biodegradable fluids. Vegetable oil suppliers are using genetic engineering to produce new vegetable oils with improved stability. Ester manufacturers are considering improving ester performance by incorporating additive-type functional groups into molecular structures. The improvement in the performance quality of biodegradable hydraulic fluids will eventually lead to more applications and increased popularity of these important fluids.

Glossary of hydraulic-fluid terminology

Absolute viscosity — the ratio of shear stress to shear rate. It is a fluid's internal resistance to flow. The common unit of absolute viscosity is the poise. Absolute viscosity divided by fluid density equals kinematic viscosity.

Absorption — the assimilation of one material into another.

Additive — chemical substance added to a fluid to impart or improve certain properties.

Adsorption — adhesion of the molecules of gases, liquids, or dissolved substances to a solid surface, resulting in relatively high concentration of the molecules at the place of contact; e.g. the plating out of an anti-wear additive on metal surfaces.

Anti-foam agent — one of two types of additives used to reduce foaming in petroleum products: silicone oil to break up large surface bubbles, and various kinds of polymers to decrease the amount of small bubbles entrained in the oils.

Asperities — microscopic projections on metal surfaces resulting from normal surface-finishing processes. Interference between opposing asperities in sliding or rolling applications is a source of friction, and can lead to metal welding and scoring. Ideally, the lubricating film between two moving surfaces should be thicker than the combined height of the opposing asperities.

Bactericide — additive included in the formulations of water-mixed fluids to inhibit the growth of bacteria.

Boundary lubrication — form of lubrication between two rubbing surfaces without development of a full-fluid lubricating film. Boundary lubrication can be made more effective by including additives in the lubricating oil that provide a stronger oil film, thus preventing excessive friction and possible scoring.

Bulk modulus — the measure of a fluid's resistance to compressibility; the reciprocal of compressibility.

Cavitation — formation of a vapor pocket (bubble) due to sudden lowering of pressure in a liquid, and often causing metal erosion and eventual pump destruction.

Corrosion inhibitor — additive for protecting wetted metal surfaces from chemical attack by water or other contaminants. *Polar compounds* wet the metal surface preferentially, protecting it with a film of oil. Other compounds may absorb water by incorporating it in a water-in-oil emulsion so that only the oil touches the metal surface. Still others combine chemically with the metal to present a non-reactive surface.

Demulsibility — ability of an oil to separate from water.

Dewaxing — removal of paraffin wax from lubricating oils to improve low temperature properties, especially to lower the cloud point and pour point.

Emulsifier — additive that promotes the formation of a stable mixture, or emulsion, of oil and water. Common emulsifiers are: metallic soaps, animal and vegetable oils, and polar compounds.

Emulsion — intimate mixture of oil and water, generally of a milky or cloudy appearance. Emulsions may be of two types: oil-in water (where water is the continuous phase) or water-in-oil (where water is the discontinuous phase).

EP additive — lubricant additive that prevents sliding metal surfaces from seizing under conditions of extreme pressure (EP). At the high local temperatures associated with metal-to-metal contact, an EP additive combines chemically with the metal to form a surface film that prevents scoring that destroys sliding surfaces under high loads.

Fire-resistant fluid — hydraulic oil used especially in high-temperature or hazardous applications. Three common types of fire-resistant fluids are: water-petroleum oil emulsions, in which the water prevents burning of the petroleum constituent; water-glycol fluids; and non-aqueous fluids of low volatility, such as phosphate esters, silicones, polyolesters, and halogenated hydrocarbon-type fluids.

Full-fluid-film lubrication — presence of a continuous lubricating film sufficient to completely separate two surfaces, as distinct from boundary lubrication. Full-fluid-film lubrication is normally hydrodynamic lubrication, whereby the oil adheres to the moving part and is drawn into the area between the sliding surfaces, where it forms a pressure, or hydrodynamic wedge.

Hydraulic fluid — fluid serving as the power transmission medium in a hydraulic system. The principal requirements of a premium hydraulic fluid are proper viscosity, high viscosity index, anti-wear protection (if needed), good oxidation stability, adequate pour point, good demulsibility, rust inhibition, resistance to foaming, and compatibility with seal materials. Anti-wear oils are frequently used in compact, high-pressure, and high-capacity pumps that require extra lubrication protection.

Immiscible — incapable of being mixed without separation of phases. Water and petroleum oil are immiscible under most conditions, although they can be made miscible with the addition of a proper emulsifier.

Inhibitor — additive that improves the performance of a petroleum product through the control of undesirable chemical reactions.

Kinematic viscosity — absolute viscosity of a fluid divided by its density at the same temperature of measurement. It is the measure of a fluid's resistance to flow under gravity.

Lubricity — ability of an oil or grease to lubricate (also called *film strength*).

Miscible — capable of being mixed in any concentration without separation of phases; e.g., water and ethyl alcohol are miscible.

Newtonian fluid — fluid, such as a straight mineral oil, whose viscosity does not change with rate of flow.

Non-Newtonian fluid — fluid, such as a grease or a polymer containing oil (e.g. multi-grade oil), in which shear stress is not proportional to shear rate.

Oxidation inhibitor — substance added in small quantities to petroleum product to increase its oxidation resistance, thereby lengthening its service or storage life; also called anti-oxidant.

Polar compound — a chemical compound whose molecules exhibit electrically positive characteristics at one extremity and negative characteristics at the other. Polar compounds are used as additives in many petroleum products.

Pour point — lowest temperature at which an oil or distillate fuel will flow, when cooled under conditions prescribed by specific test methods. The pour point is 3°C (5° F) above the temperature at which the oil in a test vessel shows no movement when the container is held horizontally for five seconds.

Shear rate — rate at which adjacent layers of fluid move with respect to each other, usually expressed as reciprocal seconds.

Shear stress — frictional force overcome in sliding one layer of fluid along another, as in any fluid flow. The shear stress of a petroleum oil or other Newtonian fluid at a given temperature varies directly with shear rate (velocity). The ratio between shear stress and shear rate is constant; this ratio is termed viscosity.

Surfactant — surface-active agent that reduces interfacial tension of a liquid. A surfactant used in a petroleum oil may increase the oil's affinity for metals and other material.

Vapor pressure — pressure of a confined vapor in equilibrium with its liquid at a specified temperature; thus, a measure of a liquid's volatility.

Viscosity — measurement of a fluid's resistance to flow. The common metric unit of absolute viscosity is the poise, which is defined as the force in dynes required to move a surface one square centimeter in area past a parallel surface at a speed of one centimeter per second, with the surfaces separated by a fluid film one centimeter thick. In addition to kinematic viscosity, there are other methods for determining viscosity, including, Saybolt Universal viscosity, Saybolt Furol viscosity, Engier viscosity, and Redwood viscosity. Since viscosity varies inversely with temperature, its value is meaningless until the temperature at which it is determined is reported.

Viscosity index (V.I.) — empirical, unitless number indicating the effect of temperature changes on the kinematic viscosity of an oil. Liquids change viscosity with temperature, becoming less viscous when heated; the higher the V.I. of an oil, the lower its tendency to change viscosity with temperature.