Chapter 4
Hydraulic Fluids

4-1. Purpose of Hydraulic Fluids

a. Power transmission. The primary purpose of any hydraulic fluid is to transmit power mechanically throughout a hydraulic power system. To ensure stable operation of components, such as servos, the fluid must flow easily and must be incompressible.

b. Lubrication. Hydraulic fluids must provide the lubricating characteristics and qualities necessary to protect all hydraulic system components against friction and wear, rust, oxidation, corrosion, and demulsibility. These protective qualities are usually provided through the use of additives.

c. Sealing. Many hydraulic system components, such as control valves, operate with tight clearances where seals are not provided. In these applications hydraulic fluids must provide the seal between the low-pressure and high-pressure side of valve ports. The amount of leakage will depend on the closeness or the tolerances between adjacent surfaces and the fluid viscosity.

d. Cooling. The circulating hydraulic fluid must be capable of removing heat generated throughout the system.

4-2. Physical Characteristics

The physical characteristics of hydraulic fluids are similar to those already discussed for lubricating oils. Only those characteristics requiring additional discussion are addressed below.

a. Viscosity. As with lubricating oils, viscosity is the most important characteristic of a hydraulic fluid and has a significant impact on the operation of a hydraulic system. If the viscosity is too high then friction, pressure drop, power consumption, and heat generation increase. Furthermore, sluggish operation of valves and servos may result. If the viscosity is too low, increased internal leakage may result under higher operating temperatures. The oil film may be insufficient to prevent excessive wear or possible seizure of moving parts, pump efficiency may decrease, and sluggish operation may be experienced.

b. Compressibility. Compressibility is a measure of the amount of volume reduction due to pressure. Compressibility is sometimes expressed by the “bulk modulus,” which is the reciprocal of compressibility. Petroleum fluids are relatively incompressible, but volume reductions can be approximately 0.5 percent for pressures ranging from 6900 kPa (1000 lb/sq in) up to 27,600 kPa (4000 lb/sq in). Compressibility increases with pressure and temperature and has significant effects on high-pressure fluid systems. Problems directly caused by compressibility include the following: servos fail to maintain static rigidity and experience adverse effects in system amplification or gain; loss in efficiency, which is counted as power loss because the volume reduction due to compressibility cannot be recovered; and cavitation, which may cause metal fracture, corrosive fatigue, and stress corrosion.

c. Stability. The stability of a hydraulic fluid is the most important property affecting service life. The properties of a hydraulic fluid can be expected to change with time. Factors that influence the changes include: mechanical stress and cavitation, which can break down the viscosity improvers and cause reduced viscosity; and oxidation and hydrolysis which cause chemical changes, formation of volatile components, insoluble materials, and corrosive products. The types of additives used in a fluid must be selected carefully to reduce the potential damage due to chemical breakdown at high temperatures.

4-3. Quality Requirements

The quality of a hydraulic fluid is an indication of the length of time that the fluid's essential properties will continue to perform as expected, i.e., the fluid's resistance to change with time. The primary properties affecting quality are oxidation stability, rust prevention, foam resistance, water separation, and antiwear properties. Many of these properties are achieved through use of chemical additives. However, these additives can enhance one property while adversely affecting another. The selection and compatibility of additives is very important to minimize adverse chemical reactions that may destroy essential properties.

a. Oxidation stability. Oxidation, or the chemical union of oil and oxygen, is one of the primary causes for decreasing the stability of hydraulic fluids. Once the reactions begin, a catalytic effect takes place. The chemical reactions result in formation of acids that can increase the fluid viscosity and can cause corrosion. Polymerization and condensation produce insoluble gum, sludge, and varnish that cause sluggish operation, increase wear, reduce clearances, and plug lines and valves. The most significant contributors to oxidation include temperature, pressure, contaminants, water, metal surfaces, and agitation.

(1) Temperature. The rate of chemical reactions, including oxidation, approximately doubles for every 10 °C (18 °F) increase in temperature. The reaction may start at a local area where the temperature is high. However, once started, the oxidation reaction has a catalytic effect that causes the rate of oxidation to increase.

(2) Pressure. As the pressure increases, the fluid viscosity also increases, causing an increase in friction and heat generation. As the operating temperature increases, the rate of oxidation increases. Furthermore, as the pressure increases, the amount of entrained air and associated oxygen also increases. This condition provides additional oxygen to accelerate the oxidation reaction.

(3) Contaminants. Contaminants that accelerate the rate of oxidation may be dirt, moisture, joint compounds, insoluble oxidation products, or paints. A 1 percent sludge concentration in a hydraulic fluid is sufficient to cause the fluid to oxidize in half the time it would take if no sludge were present. Therefore the contaminated fluid's useful life is reduced by 50 percent.

(4) Water and metal. Certain metals, such as copper, are known to be catalysts for oxidation reactions, especially in the presence of water. Due to the production of acids during the initial stages of oxidation, the viscosity and neutralization numbers increase. The neutralization number for a fluid provides a measure of the amount of acid contained in a fluid. The most commonly accepted oxidation test for hydraulic fluids is the ASTM Method D 943 Oxidation Test. This test measures the neutralization number of oil as it is heated in the presence of pure oxygen, a metal catalyst, and water. Once started the test continues until the neutralization number reaches a value of 2.0. One series of tests provides an indication of how the neutralization number is affected by contaminants. With no water or metal contaminants, the neutralization number reached 0.17 in 3500 hours. When the test was repeated with copper contaminant, the neutralization number reached a value of 0.89 after 3000 hours. The test was subsequently repeated with copper and water contamination and the neutralization number reached 11.2 in approximately 150 hours.

(5) Agitation. To reduce the potential for oxidation, oxidation inhibitors are added to the base hydraulic fluid. Two types of inhibitors are generally used: chain breakers and metal deactivators. Chain breaker inhibitors interrupt the oxidation reaction immediately after the reaction is initiated. Metal deactivators reduce the effects of metal catalysts.

b. Rust and corrosion prevention. Rust is a chemical reaction between water and ferrous metals. Corrosion is a chemical reaction between chemicals (usually acids) and metals. Water condensed from entrained air in a hydraulic system causes rust if the metal surfaces are not properly protected. In some cases water reacts with chemicals in a hydraulic fluid to produce acids that cause corrosion. The acids attack and remove particles from metal surfaces allowing the affected surfaces to leak, and in some cases to seize. To prevent rust, hydraulic fluids use rust inhibitors that deposit a protective film on metal surfaces. The film is virtually impervious to water and completely prevents rust once the film is established throughout the hydraulic system. Rust inhibitors are tested according to the ASTM D 665 Rusting Test. This test subjects a steel rod to a mixture of oil and salt water that has been heated to 60 °C (140 °F). If the rod shows no sign of rust after 24 hours the fluid is considered satisfactory with respect to rust-inhibiting properties. In addition to rust inhibitors, additives must be used to prevent corrosion. These additives must exhibit excellent hydrolytic stability in the presence of water to prevent fluid breakdown and the acid formation that causes corrosion.

c. Air entrainment and foaming. Air enters a hydraulic system through the reservoir or through air leaks within the hydraulic system. Air entering through the reservoir contributes to surface foaming on the oil. Good reservoir design and use of foam inhibitors usually eliminate surface foaming.

(1) Air entrainment is a dispersion of very small air bubbles in a hydraulic fluid. Oil under low pressure absorbs approximately 10 percent air by volume. Under high pressure, the percentage is even greater. When the fluid is depressurized, the air produces foam as it is released from solution. Foam and high air entrainment in a hydraulic fluid cause erratic operation of servos and contribute to pump cavitation. Oil oxidation is another problem caused by air entrainment. As a fluid is pressurized, the entrained air is compressed and increases in temperature. This increased air temperature can be high enough to scorch the surrounding oil and cause oxidation.

(2) The amount of foaming in a fluid depends upon the viscosity of the fluid, the source of the crude oil, the refinement process, and usage. Foam depressants are commonly added to hydraulic fluid to expedite foam breakup and release of dissolved air. However, it is important to note that foam depressants do not prevent foaming or inhibit air from dissolving in the fluid. In fact, some antifoamants, when used in high concentrations to break up foam, actually retard the release of dissolved air from the fluid.

d. Demulsibility or water separation. Water that enters a hydraulic system can emulsify and promote the collection of dust, grit, and dirt, and this can adversely affect the operation of valves, servos, and pumps, increase wear and corrosion, promote fluid oxidation, deplete additives, and plug filters. Highly refined mineral oils permit water to separate or demulsify readily. However, some additives such as antirust treatments actually promote emulsion formation to prevent separated water from settling and breaking through the antirust film.

e. Antiwear properties.

(1) Conventional hydraulic fluids are satisfactory for low-pressure and low-speed applications. However, hydraulic fluids for high-pressure (over 6900 kPa or 1000.5 lb/sq in) and high-speed (over 1200 rpm) applications that use vane or gear pumps must contain antiwear additives. These applications

do not permit the formation of full fluid film lubrication to protect contacting surfaces--a condition known as boundary lubrication. Boundary lubrication occurs when the fluid viscosity is insufficient to prevent surface contact. Antiwear additives provide a protective film at the contact surfaces to minimize wear. At best, use of a hydraulic fluid without the proper antiwear additives will cause premature wear of the pumps and cause inadequate system pressure. Eventually the pumps will be destroyed.

(2) Quality assurance of antiwear properties is determined through standard laboratory testing. Laboratory tests to evaluate antiwear properties of a hydraulic fluid are performed in accordance with ASTM D 2882. This test procedure is generally conducted with a variety of high-speed, high-pressure pump models manufactured by Vickers or Denison. Throughout the tests, the pumps are operated for a specified period. At the end of each period the pumps are disassembled and specified components are weighed. The weight of each component is compared to its initial weight; the difference reflects the amount of wear experienced by the pumps for the operating period. The components are also inspected for visual signs of wear and stress.

4-4. Use of Additives

Many of the qualities and properties discussed above are achieved by the product manufacturer's careful blending of additives with base oil stocks. Because of incompatibility problems and the complex interactions that can occur between various additives, oil producers warn users against attempting to enhance oil properties through indiscriminate use of additives. The various types of additives and their use are discussed in Chapter 7.

4-5. Types of Hydraulic Fluids

a. Petroleum. Petroleum-based oils are the most commonly used stock for hydraulic applications where there is no danger of fire, no possibility of leakage that may cause contamination of other products, no wide temperature fluctuations, and no environmental impact.

b. Fire resistant. In applications where fire hazards or environmental pollution are a concern, water-based or aqueous fluids offer distinct advantages. The fluids consist of water-glycols and water-in-oil fluids with emulsifiers, stabilizers, and additives. Due to their lower lubricity, piston pumps used with these fluids should be limited to 20,670 kPa (3000 lb/sq in.) Furthermore, vane pumps should not be used with water-based fluid unless they are specifically designed to use such fluids.

(1) Water-glycol. Water-glycol fluids contain from 35 to 60 percent water to provide the fire resistance, plus a glycol antifreeze such as ethylene, diethylene, or propylene which is nontoxic and biodegradable, and a thickener such as polyglycol to provide the required viscosity. These fluids also provide all the important additives such as antiwear, foam, rust, and corrosion inhibitors. Operating temperatures for water-glycol fluids should be maintained below 49 °C (120 °F) to prevent evaporation and deterioration of the fluid. To prevent separation of fluid phases or adverse effects on the fluid additives, the minimum temperature should not drop below 0 ^{0}C (32 ^{0}F).

(a) Viscosity, pH, and water hardness monitoring are very important in water-glycol systems. If water is lost to evaporation, the fluid viscosity, friction, and operating temperature of the fluid will increase. The end result is sluggish operation of the hydraulic system and increased power consumption. If fluid viscosity is permitted to drop due to excessive water, internal leakage at actuators will increase and cause sluggish operation. A thin fluid is also more prone to turbulent flow which will increase the potential for erosion of system components.

(b) Under normal use, the fluid pH can be expected to drop due to water evaporation, heat, and loss of corrosion inhibitors. The fluid pH should be slightly alkaline (i.e., above pH8) to prevent rust. However, because of their volatility and toxicity, handling of the amine additives that stabilize the pH is not recommended. Therefore, these essential additives are not usually replenished. Fluids with pH levels that drop below 8 should be removed and properly discarded.

(c) Make-up water added to the system must be distilled or soft deionized. The calcium and magnesium present in potable water will react with lubricant additives causing them to floc or come out of solution and compromise the fluid's performance. When this condition occurs the fluid is permanently damaged and should be replaced. To prolong the fluid and component life, water added to the system should have a maximum hardness of 5 parts per million (ppm).

(2) Water-oil emulsions

(a) Oil-in-water. These fluids consist of very small oil droplets dispersed in a continuous water phase. These fluids have low viscosities, excellent fire-resistance, and good cooling capability due to the large proportion of water. Additives must be used to improve their inherently poor lubricity and to protect against rust.

(b) Water-in-oil. The water content of water-in-oil fluids may be approximately 40 percent. These fluids consist of very small water droplets dispersed in a continuous oil phase. The oil phase provides good to excellent lubricity while the water content provides the desired level of fire-resistance and enhances the fluid cooling capability. Emulsifiers are added to improve stability. Additives are included to minimize rust and to improve lubricity as necessary. These fluids are compatible with most seals and metals common to hydraulic fluid applications. The operating temperature of water-in-oil fluids must be kept low to prevent evaporation and oxidation. The proportion of oil and water must be monitored to ensure that the proper viscosity is maintained especially when adding water or concentrated solutions to the fluid to make up for evaporation. To prevent phase separation, the fluid should be protected from repeated cycles of freezing and thawing.

(c) Synthetic fire-resistant fluids. Three types of synthetic fire-resistant fluids are manufactured: phosphate esters, chlorinated (halogenated) hydrocarbons, and synthetic base (a mixture of these two). These fluids do not contain water or volatile materials, and they provide satisfactory operation at high temperatures without loss of essential elements (in contrast to water-based fluids). The fluids are also suitable for high-pressure applications. Synthetic fluids have a low viscosity index, anywhere from 80 to -400, so their use should be restricted to relatively constant operating temperatures. When required to operate at low temperatures, these fluids may require auxiliary heating. Synthetic fluids also have high specific gravities so pump inlet conditions must be carefully selected to prevent cavitation. Phosphate esters have flash points above 204 °C (400 °F) and auto-ignition temperatures above 483 °C (900 °F), making these fluids less likely to ignite and sustain burning. Halogenated hydrocarbon fluids are inert, odorless, nonflammable, noncorrosive, and have low toxicity. Seal compatibility is very important when using synthetic fluids. Most commonly used seals such as Nitrile (Buna) and Neoprene are not compatible with these fluids.

c. Environmentally acceptable hydraulic fluids. The requirements for biodegradable fluids are discussed in Chapter 8.

4-6. Cleanliness Requirements

Due to the very small clearances and critical nature of hydraulic systems, proper maintenance and cleanliness of these systems is extremely important. Hydraulic system cleanliness codes, oil purification, and filtration are discussed in Chapter 12.