Section 10
BASIC HYDRAULICS

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Hydraulic Fluids

The most common hydraulic fluid is refined from petroleum because of its relatively low cost, inherent film strength and lubricity for protection of components. Refining techniques alone can produce fluid of moderate quality; chemical additives confer additional properties. Important characteristics of a petroleum-based hydraulic fluid might include:

- Viscosity
- Viscosity index
- Anti-wear qualities
- Pour point
- Flash point
- Fire point
- Anti-foam propensity
- Demulsibility
- Oxidation resistance
- Neutralization number

Although each of these terms is defined in the glossary, three things should be emphasized. First, viscosity is the single most important characteristic listed because it is an indicator of film strength. Second, not all of these qualities are considered important in every application. For instance, pour point would be important in a cold climate, but not in a desert situation. Third, since all of the qualities listed can be measured by standard ASTM tests, periodic testing should be conducted to ensure correspondence with the manufacturer's published data. It is unwise to assume that each new batch meets the specifications, so this data should always be kept on file. It is not necessary to test all parameters each time; instead, they may be varied until all the critical ones have been checked over a period of six months to one year. Not all oil suppliers are equally vigilant with regard to quality control.

A user does not necessarily need to maintain a lab for checking incoming oil or oil-in-service; though samples must ordinarily be mailed to them, independent labs are increasingly accessible. Their independence becomes important if disagreement develops between supplier and user.

Evaluating the most important properties of a premium hydraulic oil can be confusing. Fortunately, even if one chooses not to do extensive testing, hydraulic oil is easily rated for quality. Because certain organizations that sell hydraulic systems or hydraulically-operated equipment have a vested interest in seeing that their customers use high-quality oils, they have developed their own specifications for hydraulic fluids, and they issue approvals for products developed to their specifications by the oil companies. Purchasing products only from their approval lists provides reasonable assurance of quality. In the alternative, the end user may write a specification for hydraulic oil and ask the supplier to meet it, in which case the specification can be circulated among several oil companies to encourage competition.

After the oil has been purchased and placed in service, oil quality must be checked periodically. Representative tests might include:

- ISO contamination level
- additive level
- water
- wear metals
- ferrography
- viscosity
- neutralization number

Buying quality oil, then putting it into the system and ignoring it is foolish. Checking it at regular intervals is a must. There are right and wrong ways of taking oil samples. Ref. 1 includes a very good explanation of proper procedures and other procedures are available from labs that perform contamination testing. All of these procedures underscore the need for extra care to ensure that the sample represents the actual fluid in the hydraulic system. Ignoring these
important procedures can easily distort results or make them meaningless.

The next important point is that where fire is a possibility, a fire-resistant hydraulic fluid should be considered. These fluids are available in two forms: aqueous and non-aqueous, each briefly discussed.

**Fire-Resistant Fluids**

The term “fire-resistant” means that under certain conditions the fluid burns; if the source of ignition is removed, the flames go out. “Fireproof,” on the other hand, means that the fluid will not burn at all. In this section, we will be discussing several fluids in both categories:

**Aqueous (with water)**

- HWBF (fireproof)*
  - a. 95/5 types (oil-in-water and synthetic water additives)
  - b. Microemulsions

**Non-Aqueous (all fire-resistant)**

- Phosphate ester
- Polyol ester
- Synthetic blends

*In dilute, not concentrate form

**Aqueous Fluids**

**HWBF**

Oil-in-water emulsions and high-water based fluids generally consist of 95% water with 5% product. Additives disperse the oil evenly throughout the water, usually turning the mixture milky white. The water affords fire resistance and the oil affords a small measure of lubricity to pumps and other parts in the system; because these substances exhibit low lubricity and viscosity (near that of water), the systems in which they are used require specially designed equipment. These fluids are fireproof, but they must be protected from freezing in cold weather. Generally, they are used on older systems where high leakage is unavoidable.

Microemulsions are available in thickened and unthickened versions. A synthetic material that offers some antiwear properties for the equipment replaces the oil. The unthickened versions, with viscosity near that of water, are limited to systems designed to work with water, such as power piston pumps (duplex or triplex types). The thickened versions, with viscosity in the 200-300 SSU range at 100°F, can operate in systems with conventional components, including vane pumps. Both types must have freeze protection in winter. Operating pressures range from about 1000 psi for the unthickened version to about 2000 psi for the thickened version.

**Water-glycols** are formulated with 36-50% water. They are four-component fluids consisting of glycol (ethylene, diethylene, etc.), polyglycol polyme; additives (anti-corrosion and anti-wear) and water. The poly(chmer acts as a thickener to give these fluids viscosity; they have a viscosity index above 200 and excellent low-temperature properties. Water-glycol fluids offer excellent fire resistance and good pump life (somewhat shorter than that of mineral oil) and work well in conventional equipment up to 3000 psi or more. Newer versions on the market may be able to operate at even higher pressures.

Maintenance of water-glycol fluids is very simple. It is important to remember that if the water content falls below 36%, fire resistance drops and the glycol portion will burn. However, as the water content evaporates, viscosity rises, so simply checking the viscosity and matching it against a curve furnished by the manufacturer will yield an estimate of water content. Or a drop placed on a special refractometer will give a BRIX number that can be related to water content on a graph furnished by the manufacturer. When water is added back, it must be distilled, deionized or soft water, not tap water; consult with the supplier for the exact properties required. Finally, the alkaline reserves of water-glycol fluids should be monitored to ensure that the corrosion protection additives have not been depleted.

**Invert or water-in-oil emulsions are fire-resistant fluids that contain 38-42% water. They are called invert because oil is the continuous phase with water droplets dispersed throughout; this is the opposite of the oil-in-water emulsions mentioned above. Invert emulsions, ordinarily used below 2000 psi, have a higher viscosity (300 SSU) than most hydraulic fluids. They are generally used within a limited temperature range, from 0°F (with an anti-freeze added) to about 130°F; their principal advantage is that, except for HWBF, they are the least expensive water-based fluids.**

Excess water thickens invert emulsion fluids; near 60% water, they reach the viscosity of mayonnaise. Excess water may also cause the fluid to revert to a continuous water phase, in which the fluid has about the same lubricity as water. The bacteria that thrive in these fluids are best controlled by keeping the pH value alkaline, above 8.0. It is apparent that these fluids need more maintenance than other water-based fluids.

**Non-Aqueous Fluids**

Phosphate ester fluids are synthetic fire-resistant hydraulic fluids formulated by reacting an alcohol with an acid. All are good to excellent lubricants, with good film strength and anti-wear properties. But water contamination must be kept below 0.2%; otherwise, these fluids will react to form acids. Compared to petroleum oil hydraulic fluids, phosphate esters are expensive (see chart below); they have the following characteristics:

- Specific gravity greater than 1.00
- Low viscosity index, less than 90; limited in low-temperature service
- Auto-ignition temperature near 1000°F
- Flash point 480-500°F; fire point 600-610°F
- Pump wear < 7.0 mg wear (ASTM D-2882 test)
- Maximum operating temperature should not exceed 150°F
- Need special seals, like viton
Polyol ester fluids, also fire-resistant, are formed by the reaction of a fatty acid with an alcohol. Though they are good lubricants, they react with water in much the same manner as phosphate esters. Other characteristics include:

- Specific gravity of .91; floats on water in collection pits
- High viscosity index, over 150
- Auto-ignition temperature of 760°F
- Flash point 530-550°F; fire point 600-615°F
- Pump wear < 15 mg. wear (ASTM D-2882 test)
- Maximum operating temperature should not exceed 150°F
- Compatible with Buna-N seals

Synthetic Blends

These products are mixtures of an ester and a petroleum oil or a polymer. Blends are formulated to improve the low-temperature characteristics of the base ester or lower the cost, or both. Though blends containing oil may not have the fire resistance of the fluids discussed above, they may be approved for specific uses by one of the agencies discussed below. Typical characteristics include:

- Minimum specific gravity of 0.98
- Minimum viscosity index of 90
- Auto-ignition temperature of 835°F
- Minimum flash point of 415°F; minimum fire point of 545°F
- Pump wear < 75 mg. wear (ASTM D-2882 test)
- Maximum operating temperature should not exceed 180°F
- Special seals, such as viton, required

Fire-Resistance Testing

Private and public agencies like Factory Mutual and the Mine Safety and Health Administration (MSHA) can test fluids for fire resistance. Since reputable companies submit their fluids for testing and advertise their approvals, users are well advised to request assurances of approval from suppliers.

Costs

The costs of these fluids increase naturally with inflation, but relative costs between categories are fairly stable. Mineral oil (1.00) was the basis for the following chart of relative prices:

- Mineral Oil 1.00
- Water-glycols 4.00-6.00
- Oil-in-water (95-5) 0.25 - 0.50
- Microemulsions 0.50 - 1.00 unthickened; 6.00 thickened
- Inverted emulsions 2.50 - 3.00
- Phosphate Esters 16.00
- Polyol Esters 9.00
- Synthetic Blends 8.00

Servo and Proportional Valves

It was noted in the discussion of directional valves above that they are generally designed for two- or three-spool positions or modes of operation. Servo and proportional valves, in contrast, have infinite positioning capability, as indicated by the two extra horizontal lines in the symbol shown in Fig. 44. Servo and high-performance proportional valves are usually applied in closed-loop systems employing "feedback." Feedback means that information about an actuator's velocity, stopping position or hydraulic pressure is detected by a transducer, "fed back" to the valve and compared with desired values of the parameter; if error (difference) is detected, corrective action can be taken to reduce it. Lower-performance proportional valves can be used in either closed-loop or open-loop systems (meaning no feedback). In an open-loop system, the operator sets controls for the acceleration, velocity or pressure desired for the actuator and determines by sight whether he has been successful. If not, the controls are readjusted. Where valve hysteresis may cause problems, a transducer can be fitted to the spool to assure that a given electrical signal will always produce a given response. This is valve feedback, not system feedback.

Pilot-operated or 2-stage servo valves are usually operated by a "torque motor" consisting of two electrical coils with opposite polarity that pull a permanent magnet armature connected to a flapper through an arc (Fig. 45). The flapper is struck on both sides by tiny jets of oil; if it is in the exact center of the gap (say, with no voltage on the coils), the pilot oil pressure is balanced, helping to center the main spool. This happens because the main spool end chambers and the pilot oil pressure chambers are connected and the pressure is determined by the proximity of the flapper to the jets, i.e., the closer the flapper is to the jets, the higher the pressure.
The flapper is also connected to the main spool by a ball on the end of the feedback spring inserted into a recess in the spool so that when the spool moves to the desired position, the flapper is centered to equalize the pilot pressure and hold the spool stationary. Of course, during this interval the flapper is bent slightly because the spool and torque motor pull it off center.

When it is desirable to return the spool to the center of the sleeve (to stop the actuator, for example), the voltage is relaxed in the torque motor and the flapper shifts to one side because the main spool is off center. When the pressure rises in the pilot line toward which the flapper shifted, the higher pressure shifts the main spool back to center, pulling the flapper with it and equalizing the pilot pressure.

Not shown in Fig. 45 is the adjusting screw that can move the sleeve surrounding the spool. This adjustment is necessary from time to time to “null” the valve, or stop actuator movement where the valve is de-energized. Also not shown is a single-stage servo operated directly by the coils and armature. Servo valves may be operated by other means, but the torque-motor style shown is by far the most popular.

REFERENCE