Kirk-Othmer Encyclopedia of Chemical Technology.

HYDRAULIC FLUIDS

The moving parts of many industrial machines are actuated by fluid that is under pressure. A system used to apply the fluid can consist of a reservoir, a motor-driven pump, control valves, a fluid motor, and piping to connect these units, eg, a hydraulic system. Generally, petroleum (qv) lubricating oils, and sometimes water are used as the pressure-transmitting or hydraulic fluids. Lubricating oil is not only suitable for pressure transmission and controlled flow, but it also minimizes friction and wear of moving parts (see Lubrication and lubricants) and protects ferrous surfaces from rusting (see Corrosion and corrosion control).

Hydraulic actuation is based on Pascal's discovery that pressure which has developed in a fluid acts equally and in all directions throughout the fluid and behaves as a hydraulic lever or force multiplier (see Pressure measurement) (1). As shown in Figure 1, a 5-kg weight acting on a 10-cm^2 piston develops a 49-kPa (7.1-psi) pressure which, when transmitted to a 100-cm^2 piston, enables that piston to support a 50-kg weight. Pressure is transmitted easily around corners, and the two cylinders can be any reasonable distance apart (2). When motion occurs, the small (10 cm^2) piston must move 10 cm in order to move the large (100 cm^2) piston 1 cm. This is necessary because in this closed system the volume of liquid leaving one cylinder must equal the volume of liquid entering the other cylinder.

Following the invention of the hydraulic press in 1795 (3), the use of hydraulics expanded rapidly during the nineteenth century. The weight-loaded accumulator, invented ca 1850, was used to store energy in hydraulic systems. The elementary press circuit has several parts that are common to all hydraulic systems; a reservoir, a pump, piping, control valves, a motor, which in this case is a hydraulic cylinder or ram, and the hydraulic fluid. By ca 1860 hydraulic presses were used for forging, and an adjustable-speed hydraulic transmission was perfected in 1906 (2). The manufacture of hydraulically actuated machines attained industrial importance after 1920.

In 1840 a hydraulic power network, which involved large reciprocating pumps that were driven by steam engines, supplied fluid power to London. However, concurrent technology in steam (qv) turbines and the electric generators outmoded such networks until hydraulic systems were improved with the use of rotary pumps and oil. The rotary piston pump marked the transition from use of water to oil as the hydraulic fluid (4). The use of vacuum-distilled, refined mineral oils were instrumental in the success of rotary axial piston pumps and motors such as the Waterbury variable speed gear (5).

Hydraulic circuits have been used in numerous combinations in many industrial machines. Speed can be readily controlled by controlling the volume of fluid flow, and can be adjusted during operation, eg, rapid approach, slow cut or press, and rapid retraction are obtained easily. Force can be applied in any direction, transmitted around corners and to remote parts of a machine, and can be controlled easily by controlling fluid pressure. Great force is available with or without motion. Direction of movement is controlled by regulation of the direction of fluid flow. Smooth operation using inherent cushioning effect and protection against overload through oil-pressure relief is characteristic. Energy can be stored to meet sudden demands, and equipment is highly adaptable to remote and automatic control.

For proper operation under anticipated use, recommended lubricants are designated by the equipment designer, ie, the designer specifies both the type of fluid and the fluid's viscosity.

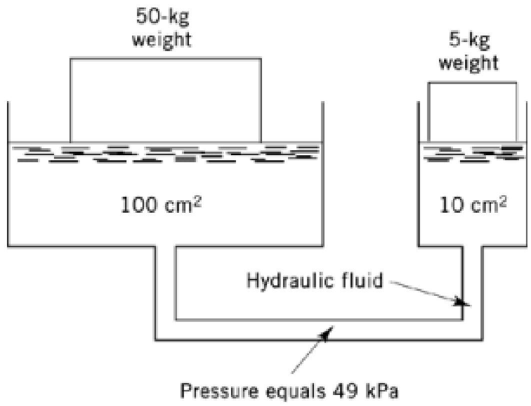


Fig. 1. Basis for hydraulic operation.

Table 1. ISO Viscosity Classification

	Kinematic viscosity,[a] mm^2/s (=cS)		
ISO VG	Minimum	Midpoint	Maximum
2	1.98	2.2	2.42
3	2.88	3.2	3.52
5	4.14	4.6	5.06
7	6.12	6.8	7.48
10	9.00	10	11.0
15	13.5	15	16.5
22	19.8	22	24.2
32	28.8	32	35.2
46	41.4	46	50.6
68	61.2	68	74.8
100	90.0	100	110
150	135	150	165
220	198	220	242
320	288	320	352
460	414	460	506
680	612	680	748
1000	900	1000	1100
1500	1350	1500	1650

[a] At 40°C.

1. Viscosity Classification

The viscosity classification for hydraulic fluids and other industrial liquid lubricants is defined by ASTM D2422 (ISO STD 3448), which establishes 18 viscosity grades in the range of $2 - 1500\ mm^2/s$ (=cS) covering approximately the range from kerosene to cylinder oils. Classification is based on the principle that the midpoint kinematic viscosity of each grade should be about 50% higher than that of the preceding one. Using this numbering system, viscosities are quoted as ISO viscosity grade (ISO VG) as shown in Table 1 (see also Rheological measurements).

Different fluids have different rates of change in viscosity with temperature. The viscosity index (VI), a method of applying a numerical value to this rate of change, is based on a comparison with the relative rates of change of two arbitrarily selected types of oils that differ widely in this characteristic. A high VI indicates a relatively low rate of change of viscosity with temperature; a low VI indicates a relatively high rate of change of viscosity with temperature. A standard method for calculating the viscosity index is described in ASTM D2270.

2. Types

Antiwear premium hydraulic fluids represent the largest volume of hydraulic fluids used. Shortly after their introduction in 1960, a second product group was formulated, characterized by the same antiwear characteristics but having lower pour points and higher viscosity indexes. These were formulated for use in mobile and marine applications subject to temperature extremes.

The largest volume of hydraulic fluids are mineral oils containing additives to meet specific requirements. These fluids comprise over 80% of the world demand (ca 3.6×10^9 L (944×10^6 gal)). In contrast world demand for fire-resistant fluids is only about 5% of the total industrial fluid market. Fire-resistant fluids are classified as high water-base fluids, water-in-oil emulsions, glycols, and phosphate esters. Polyolesters having shear-stable mist suppressant also meet some fire-resistant tests.

2.1. Mineral Oil-Based Fluids

Premium mineral oils are ideally suited for use in most hydraulic systems and are, by themselves, excellent hydraulic fluids. They are high viscosity index (VI) oils available in a wide range of viscosity grades. Unusually high VI products are especially suitable for use under low temperature conditions. All of the oils contain additives, eg, rust and oxidation inhibitors and antiwear materials. In the event that the additives are consumed or removed in service, these oils would continue to serve effectively for long periods. The oils are carefully processed to have good water-separating ability and resistance to foaming. Because of high oxidation resistance, these qualities are maintained over long service periods.

2.2. Lubricating Oils

Lubricating oils generally include all classes of lubricating materials that are applied as fluids. Nearly all of the world's lubricating oils are made from the more viscous portion of crude oil which remains after removal of gas oil and lighter fractions by distillation. However, the crude oils from various parts of the world differ widely in properties and appearance, although there is relatively little difference in their elemental analysis. Much of the variation in physical characteristics and performance qualities of lubricating oils prepared from different crude sources can be accounted for by the variations that can exist in a single large hydrocarbon molecule. In order to minimize these variations to yield products that provide consistent performance in specific applications, four steps are followed in the manufacture of finished lubricating oils from the various available crudes: (*1*) selection and segregation of crudes according to the principal types of hydrocarbons present; (*2*) distillation of the crude to separate it into fractions containing hydrocarbons in the same boiling point range; (*3*) processing to remove undesirable constituents from the various fractions or to convert some of these materials to more desirable materials; and (*4*) blending to attain the physical characteristics that are required in the finished products and incorporating chemical agents to improve performance.

Factors in lube crude selection are supply (available quantities and constancy of composition), refining, production, and marketing. Two base stocks that are similar in viscosity are listed in Table 2. One base stock is made from a cycloparaffinic, eg, naphthenic, crude oil which contains no wax and has a low (-46°C) pour point. In contrast, the paraffinic stock requires dewaxing to reduce its pour point from about +27 to -18°C. Although both oils have identical viscosities at 38°C, the viscosity of the cycloparaffinic oil is affected much more by temperature change than that of the paraffinic stock. This is reflected in the lower viscosity index of the cycloparaffinic oil. For products that operate over a wide temperature range, eg, automotive engine oils, the

Table 2. Lube-Base Stocks[a]

Property	Cycloparaffinic	Paraffinic
viscosity at 38°C, mm^2/s (= cS)	20.5	20.5
pour point, °C	−46	−18
viscosity index	15	100
flash point, °C	171	199
specific gravity	0.9075	0.8615
color, ASTM	1.5	0.5

[a] Ref. 6.

Table 3. Compressibility and Thermal Conductivity Characteristics[a]

Fluid type	Compression[b] at 70 MPa,[c] %	Nominal thermal conductivity, J/(cm·s·°C) × 10^{-3}
mineral oil	3.3	0.77
phosphate ester	2.5	1.27
water–glycol	2.6	2.29
water-in-oil emulsions	3.5	
water	3.3	3.68[d]

[a] Ref. 8.
[b] Expressed as a percent reduction in volume.
[c] To convert MPa to psi, multiply by 145.
[d] At 50°C.

cycloparaffinic stock is less desirable. The long-term supply of cycloparaffinic crudes is limited, and alternatives are being sought to replace them.

2.3. Fire-Resistant Hydraulic Fluids

The four classifications of fire-resistant hydraulic fluids are listed below (7). Three of the four groups are fire resistant because they contain a significant amount of water which provides cooling and blanketing of the combustible materials.

Classification	Description
HF-A	high water content fluids (95/5 fluids); contain a maximum of 20% combustible material; range from milky to transparent in appearance
HF-B	water-in-oil (invert) emulsions: contain a maximum of 60% combustible material; water content normally is 40 or 45% with the continuous phase being the oil component; white, milky fluid
HF-C	water—glycol solutions; usually contain at least 35% water; transparent and are usually dyed
HF-D	water-free, pure chemical fluids; most common are phosphate esters; other types exist such as mist-suppressed polyol esters

The compressibility and thermal conductivity of mineral oils is compared to fire-resistant fluids in Table 3. All good hydraulic fluids must resist compression, and many fire-resistant fluids can operate at a lower temperature than mineral oils because of improved thermal conductivity.

Some of the tests and criterion used to define fire resistance may be found in the literature (9). Additionally, the compression—ignition and hot manifold tests as defined in MIL-H-19457 and MIL-H-5606, respectively; the Wick test as defined by Federal Standards 791, Method 352; flash point and fire point as defined in ASTM

D92; autoignition temperature as defined in ASTM D2155; and linear flame propagation rate are defined in ASTM D5306 are used.

2.3.1. High Water-Base Fluids

These water-base fluids have very high fire resistance because as little as 5% of the fluid is combustible. Water alone, however, lacks several important qualities as a hydraulic fluid. The viscosity is so low that it has little value as a sealing fluid; water has little or no ability to prevent wear or reduce friction under boundary-lubrication conditions; and water cannot prevent rust. These shortcomings can be alleviated in part by use of suitable additives. Several types of high water-based fluids commercially available are soluble oils, ie, oil-in-water emulsions; microemulsions; true water solutions, called synthetics; and thickened microemulsions. These last have viscosity and performance characteristics similar to other types of hydraulic fluids.

2.3.2. Water-in-Oil Emulsions

A water-in-oil or invert emulsion consists of a continuous oil phase which surrounds finely divided water droplets that are uniformly dispersed throughout the mixture. The invert emulsion ensures that the oil is in constant contact with the hydraulic system's moving parts, so as to minimize wear.

The fluid is formulated from a premium mineral oil-base stock that is blended with the required additive to provide antiwear, rust and corrosion resistance, oxidation stability, and resistance to bacteria or fungus. The formulated base stock is then emulsified with ca 40% water by volume to the desired viscosity. Unlike oil-in-water emulsions the viscosity of this type of fluid is dependent on both the water content, the viscosity of the oil, and the type of emulsifier utilized. If the water content of the invert emulsion decreases as a result of evaporation, the viscosity decreases; likewise, an increase in water content causes an increase in the apparent viscosity of the invert emulsion; at water contents near 50% by volume the fluid may become a viscous gel. A hydraulic system using a water-in-oil emulsion should be kept above the freezing point of water if the water phase does not contain an antifreeze. Even if freezing does not occur at low temperatures, the emulsion may thicken, or break apart with subsequent dysfunction of the hydraulic system.

2.3.3. Water—Glycol Solutions

These materials are transparent solutions of water and glycol having good low temperature properties. They frequently contain water-soluble additives to improve performance in corrosion resistance, anti-wear, etc. A water-soluble polymer is commonly utilized to boost viscosity. As solutions their advantage over emulsions is their inherent stability.

2.3.4. Other Fire-Resistant Hydraulic Fluids

Phosphate and more recently polyol esters are marketed as fire-resistant compounds. They are formulated with additives to control wear, oxidation, corrosion, and misting. Seal compatibility and solvency characteristics of these fluids may be quite different from those of mineral oils.

3. Synthetic Fluids

The starting materials for synthetic lubricants are synthetic base stocks, often manufactured from petroleum, made by synthesizing compounds which have adequate viscosity for use as lubricants. The process of combining individual units can be controlled so that a large proportion of the finished base fluid is comprised of one or only a few compounds. Depending on the starting materials and the combining process that is used, the compound (or compounds) can have the properties of the most effective compounds in a mineral-base oil. It can also have

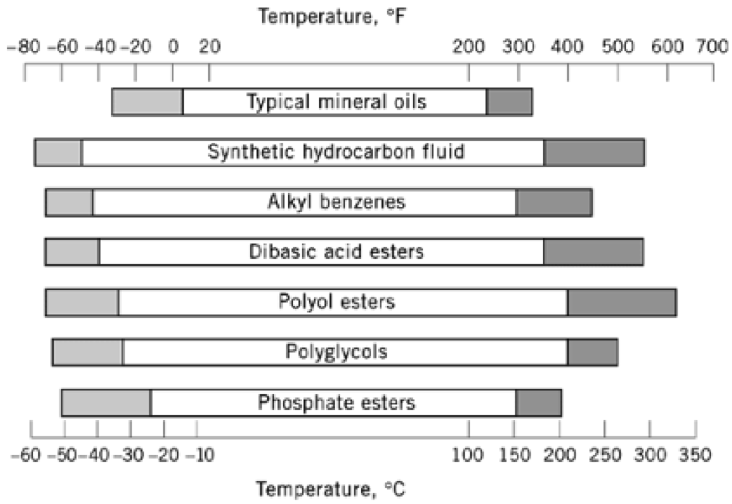


Fig. 2. Comparative temperature limits of mineral oil and synthetic lubricant, where □ represents continuous service; ▬ service dependent on starting torque; and ▬ intermittent service (6).

unique properties, eg, miscibility with water or refrigerant, or complete nonflammability, that are not found in any mineral oil.

The primary performance features of synthetic lubricants are outstanding flow characteristics at extremely low temperatures and stability at extremely high temperatures. The comparative operating temperature limits of mineral oil and synthetic lubricants are shown in Figure 2; other advantages, as well as limiting properties, are outlined in Table 4. Synthesized hydrocarbons, organic esters, polyglycols, and phosphate esters account for over 90% of the volume of synthetic lubricant bases in use. Other synthetic lubricating fluids include a number of materials that generally are used in low volumes.

Table 4. Advantages and Limiting Properties of Synthetic Base Stocks[a]

Stock	Potential advantages	Possible limiting properties
synthetic hydrocarbon fluids	high temperature stability; long life; low temperature fluidity; high viscosity index; low volatility oil economy; compatibility with mineral oils and paints; no wax; hydrolytic stability	solvency—detergency;[b] seal compatibility[b]
alkylated benzenes	low temperature fluidity; low volatility; high temperature stability; hydrolytic stability	lubricity; solvency—detergency; low viscosity index
organic esters	high temperature stability; long life; low temperature fluidity; solvency—detergency	seal compatibility;[b] mineral oil compatibility;[b] antirust;[b] antiwear and extreme pressure;[b] hydrolytic stability; paint compatibility
phosphate esters	fire resistant; lubricating ability	seal compatibility; low viscosity index; paint compatibility; metal corrosion;[b] hydrolytic stability
polyglycols	water versatility; high viscosity index; low temperature fluidity; antirust; no wax	mineral oil compatibility; paint compatibility; oxidation stability[b]

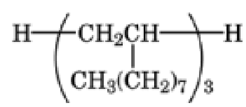
[a] Comparisons are made on basestocks without additive packages.
[b] Limiting properties of synthetic base fluids which can be overcome by formulation chemistry.

3.1. Hydrocarbons

Synthesized hydrocarbons are the most popular of the synthetic base stocks. These are pure hydrocarbons (qv) and are manufactured from raw materials derived from crude oil. Three types are used: olefin oligomers, alkylated aromatics, and polybutenes. Other types, such as cycloaliphatics, are also used in small volumes in specialized applications.

3.1.1. Olefin Oligomers

Olefin oligomers (poly-α-olefins) are formed by combining a low molecular weight material, usually ethylene (qv), into a specific olefin which is oligomerized into a lubricating oil-type material and then is hydrogen-stabilized. In the oligomerization, a few (usually 3–10) of the basic building block molecules are combined to form the finished material. Therefore, the product may be formed having varying molecular weights and attendant viscosities to meet a broad range of requirements. A typical olefin oligomer-base oil molecular is the oligomer of 1-decene:



Olefin oligomers are a special type of paraffinic mineral oil comparable in properties to the most effective components found in petroleum-derived base oils (see Olefin polymers). These oligomers have high (usually >135) viscosity indexes, excellent low temperature fluidity, very low pour points, and excellent shear and hydrolytic stability. Because of the saturated nature of the hydrocarbons, both the oxidation and thermal stability are good. Volatility is lower than that of comparably viscous mineral oils and evaporation loss at elevated temperatures is lower. In many applications, it is important that olefin oligomers are similar in composition to and compatible with mineral oils as well as with additive systems developed and machines designed to operate on mineral oils. The olefin oligomers do not cause any softening or swelling of typical seal materials; however, formulation of finished lubricants can promote a softening or seal swell effect, if desired (see Olefins, higher).

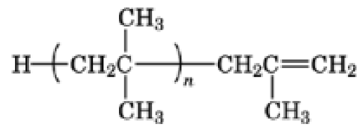
3.1.2. Alkylated Aromatics

The alkylation (qv) process involves joining linear or branched alkyl groups to an aromatic molecule, usually benzene. Generally, the alkyl groups that are used contain from 10–14 carbon atoms and have normal paraffinic configurations. The properties of the product can be altered by changing the structure and position of the alkyl groups. Dialkylated benzene is a typical alkylated aromatic used as a lubricating oil.

Alkylated aromatics have excellent low temperature fluidity and low pour points. The viscosity indexes are lower than most mineral oils. These materials are less volatile than comparably viscous mineral oils, and more stable to high temperatures, hydrolysis, and nuclear radiation. Oxidation stability depends strongly on the structure of the alkyl groups (10). However it is difficult to incorporate inhibitors and the lubrication properties of specific structures may be poor. The alkylated aromatics also are compatible with mineral oils and systems designed for mineral oils (see Benzene; Toulene; Xylenes and ethylbenzene).

3.1.3. Polybutenes

Polybutenes are produced by controlled polymerization of butenes and isobutene (isobutylene) (see Butylenes). A typical polyisobutylene structure is



The low molecular weight materials produced by this process are used as lubricants, whereas the high molecular weight materials, the polyisobutylenes, are used as VI improvers and thickeners. Polybutenes that are used as lubricating oils have viscosity indexes of 70–110, fair lubricating properties, and can be manufactured to have excellent dielectric properties. Above their decomposition temperature (ca 288°C) the products decompose completely to gaseous materials.

3.1.4. Cycloaliphatics

Synthesized cycloaliphatics are generally not utilized as hydraulic fluids. Cycloaliphatics are synthesized for use as traction lubricants because, under high stress, they have high traction coefficients and excellent stability. A typical cycloaliphatic used as a synthetic traction fluid is 2,3-dicyclohexyl-2,3-dimethylbutane [5171-88-0], $C_{18}H_{34}$.

Substituted cyclopentane lubricants have been commercialized using cyclopentadiene as starting material. These specialty aerospace lubricants have low volatility and desirable optical properties.

3.2. Organic Esters

3.2.1. Dibasic Acid Esters

Dibasic acid esters (diesters) are prepared by the reaction of a dibasic acid with an alcohol that contains one reactive hydroxyl group (see Esters, organic). The backbone of the structure is formed by the acid. The alcohol radicals are joined to the ends of the acid. The physical properties of the final product can be varied by using different alcohols or acids. Compounds that are typically used are adipic, azelaic, and sebacic acids and 2-ethylhexyl, 3,5,5-trimethylhexyl, isodecyl, and tridecyl alcohols.

Dibasic acid esters have excellent low temperature fluidity and very low pour points. Viscosity indexes usually are high, some above 140, and the products are shear stable. Generally, however, the hydrolytic stability is not as good as mineral oils. Diesters have good lubricating properties, good thermal and oxidation stability, and lower volatility than comparably viscous mineral oils. These compounds also have the ability to suspend potential deposit-forming materials so that hot metal surfaces in contact with them remain clean. However, diesters cause more seal swelling than mineral oils. Also, they may not have good solubility for additives that have been developed for use in mineral oils, although good results are obtained with additives that are developed especially for these fluids. Additionally, these may affect paints and finishes more than mineral oils (see Coatings; Paint).

3.2.2. Polyol Esters

Polyol esters are formed by the reaction of an alcohol having two or more hydroxyl groups, eg, a polyhydric alcohol and a monobasic acid. In contrast to the diesters, the polyol in the polyol esters forms the backbone of the structure and the acid radicals are attached to it. The physical properties may be varied by using different polyols or acids. Trimethylolpropane [77-99-6], $C_6H_{14}O_3$, and pentaerythritol [115-77-5], $C_5H_{12}O_4$, are two commonly used polyols (see Alcohols, polyhydric). Usually the acids that are used are obtained from animal or vegetable oils and contain 5–10 carbon atoms. Polyol esters have better high temperature stability than the diesters. The former's low temperature properties and hydrolytic stability are about the same as the latter's, but the viscosity indexes of the former may be lower. Volatility of polyol esters is equal to or lower than the diesters. The polyol esters affect paints and finishes more than mineral oils and often have different seal swelling characteristics (see also Polyesters).

3.3. Polyglycols

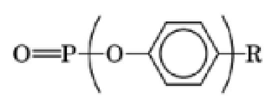
Polyglycols are the largest single class of synthetic lubricant bases and are most accurately described as polyalkylene glycol ethers (see Glycols; Polyethers). Small quantities of simple glycols, eg, ethylene glycol [107-21-1], $C_2H_6O_2$, and poly(ethylene glycol), are used as hydraulic brake fluids. Polyglycols are used in both water-soluble and water-insoluble forms. Polyglycols decompose completely to form volatile compounds under high temperature oxidizing conditions, which results in low sludge buildup under moderate-to-high operating temperatures, or complete decomposition without deposits in certain extremely hot applications.

Polyglycols have low pour points and good viscosity—temperature characteristics, although at low temperatures these materials tend to become more viscous than some of the other synthesized bases. High temperature stability is fair to good and can be improved with additives. Thermal conductivity is high. Polyglycols are not compatible with mineral oils or additives that were developed for use in mineral oils, and may have considerable affect on paints and finishes. They have low solubility for hydrocarbon gases and for some refrigerants. Seal swelling is low, but care must be exercised in seal selection with the water-soluble types to be sure that the seals are compatible with water. The glycol fluid does have a tendency to adsorb moisture from the atmosphere.

Certain polyglycols apparently have compatibility with nonozone depleting refrigerants (see Refrigeration).

3.4. Phosphate Esters

Phosphate esters are one of the larger volume classes of synthetic base fluids. A typical phosphate ester structure where R can be either an aryl or alkyl group is

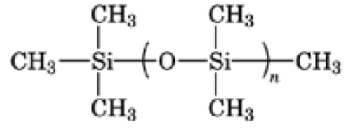


The phosphate esters have better fire resistance than mineral oils (see Flame retardants, phosphorus flame retardants). The lubricating properties are generally good; however, the high temperature stability is fair; and decomposition products can be corrosive. Generally, phosphate esters have poor viscosity—temperature characteristics, although pour points and volatility are low. Phosphate esters have considerable effect on paints and finishes and may cause swelling of many seal materials. Compatibility with mineral oils ranges from poor to good, depending on which ester is used; hydrolytic stability is fair. Phosphate esters have specific gravities greater than one which implies that water contamination tends to float rather than settle to the bottom, resulting in high pumping losses (see Phosphorus compounds).

3.5. Other Synthetic Lubricating Fluids

3.5.1. Silicones

Silicone fluids have a polymer-type structure except that the carbons in the backbone are replaced by silicon (see Silicon compounds, silicones). Dimethylpolysiloxane [9016-00-6] one of the widely used silicone fluids, has the structure



Silicones have high viscosity indexes, some ≥ 300. Pour points are low and low temperature fluidity is good. These materials are chemically inert, nontoxic, fire resistant, and water repellent, and have low volatility. Seal swelling is low. Compressibility is considerably higher than for mineral oils. The thermal and oxidation stabilities of silicones are good up to high temperatures. However, if oxidation does occur, the oxidation products, which include silicon oxides, can be abrasive. A principal disadvantage of the common silicones is that these compounds have low surface tensions which permit extensive spreading on metal surfaces, especially on steel; consequently, effective adherent lubricating films do not form. The silicones that exhibit this characteristic also show poor response to wear- and friction-reducing additives.

3.5.2. Silicate Esters

Silicate esters, $Si(OR)_4$ where R is an aryl or alkyl group, have excellent thermal stability, and using proper inhibitors, show good oxidation stability. These have excellent viscosity—temperature characteristics, and the pour points and volatilities are low. Silicate esters have only fair lubricating properties, however, because resistance to hydrolysis is poor (see Silicon compounds, esters).

3.5.3. Halogenated Fluids

Chlorocarbons, fluorocarbons, or combinations of the two are used to form lubricating fluids (see Chlorocarbons and chlorohydrocarbons; Fluorine compounds, organic). Generally, these fluids are chemically inert, essentially nonflammable, and often show excellent resistance to solvents. Some have outstanding thermal and oxidation stability, because they are completely unreactive even in liquid oxygen, and extremely low volatility.

4. Additives

Practically all lubricating oils contain at least one additive; some oils contain several. The amount of additive that is used varies from < 0.01 to 30% or more. Additives can have detrimental side effects, especially if the dosage is excessive or if interactions with other additives occur. Some additives are multifunctional, eg, certain VI improvers also function as pour-point depressants or dispersants. The additives most commonly used in hydraulic fluids include pour-point depressants, viscosity index improvers, defoamers, oxidation inhibitors, rust and corrosion inhibitors, and antiwear compounds.

4.1. Pour-Point Depressants

Pour-point depressants are high molecular weight polymers that inhibit formation of wax crystals which prevent oil flow at low temperatures. Two types which are used are alkylaromatic polymers, which are adsorbed by the wax crystals as they form, thereby preventing the crystals from growing and adhering to each other; and polymethacrylates, which cocrystallize with the wax thereby preventing crystal growth (see Methacrylic polymers). The additives function by lowering the temperature at which a rigid structure forms. Depending on the type of oil being treated, a pour-point depression of up to 28°C can be achieved, although a lowering of ca 11–17°C is more common.

4.2. Viscosity Index Improvers

VI improvers are long-chain, high molecular weight polymers that increase the relative viscosity of an oil at high temperatures more than at low temperatures. In cold oil the molecules of the polymer adopt a compressed coiled form so that the affect on viscosity is minimized. In hot oil the molecules swell, and interaction with the oil produces a proportionally greater thickening effect. Although the viscosity of the oil—polymer mixture decreases as the temperature increases, viscosity does not decrease as much as the oil alone would decrease.

The VI improvers are subject to degradation as a result of mechanical shearing in service. Temporary shear breakdown occurs under certain conditions of moderate shear stress and results in a temporary loss in viscosity. Under these conditions the long molecules of the VI improver align in the direction of the stress with a consequential decrease in resistance to flow. When the stress is removed, the molecules return to their usual random arrangement and the temporary viscosity loss is recovered. This effect can temporarily reduce oil friction to facilitate hydraulic startup at low temperatures. Permanent shear breakdown occurs when the shear stress ruptures the backbone of the polymer, converting the polymer into low molecular weight materials which are less effective VI improvers. This results in a permanent viscosity loss. Permanent shear breakdown generally is the limiting factor controlling the maximum amount of VI improver that can be used in a particular oil blend.

The most common VI improvers are methacrylate polymers and copolymers, acrylate polymers (see Acrylic ester polymers), olefin polymers and copolymers, and styrene—butadiene copolymers. The degree of VI improvement from these materials is a function of the molecular weight distribution of the polymer. VI improvers are used in engine oils, automatic transmission fluids, multipurpose tractor fluids, hydraulic fluids, and gear lubricants. Their use permits the formulation of products that provide satisfactory lubrication over a much wider temperature range than is possible using mineral oils alone.

4.3. Defoamers

The ability of oils to release entrained air and resist foaming varies considerably depending on the type of crude oil, type and degree of refining applied to it, and its viscosity. Silicone polymers used at a few ppm are the most widely used defoamers (qv). These materials are marginally soluble in oil and the correct choice of polymer size is critical if settling during long-term storage is to be avoided. Defoamers also may increase air entrainment in the oil. Organic polymers are sometimes used to overcome these drawbacks, although much higher concentrations are required.

4.4. Oxidation Inhibitors

When oil is heated in the presence of air, oxidation occurs. As a result of this oxidation, the oil viscosity and the concentration of organic acids in the oil increase, and varnish and lacquer deposits may form on hot metal surfaces that are exposed to the oil. In extreme cases, these deposits may be further oxidized to hard, carbonaceous materials. As the temperature increases, the rate of oxidation increases exponentially. Exposure to air, or more intimate mixing with it, also increases the rate of oxidation. Many materials, such as metals, particularly copper, and organic and mineral acids, may act as catalysts or oxidation promoters (see Heat stabilizers).

The mechanism of oil oxidation is thought to proceed by a free-radical chain reaction. Reaction-chain initiators are formed from unstable oil molecules, and these react with oxygen to form peroxy radicals which in turn attack the unoxidized oil and form new initiators and hydroperoxides. The hydroperoxides are unstable and divide, thereby forming new initiators and continuing the reaction. Oxidation inhibitors may not entirely prevent oil oxidation when conditions of exposure are severe, and only some types of oils are inhibited to a great degree. Two general types of oxidation inhibitors are those that react with the initiators, peroxy radicals and hydroperoxides, to form inactive compounds, and those that decompose these materials to form less reactive compounds. At temperatures below 93°C, oxidation proceeds slowly and inhibitors of the first type are effective. Examples are hindered (alkylated) phenols, eg, 2,6-di(*tert*-butyl)-4-methylphenol [128-37-0], $C_{15}H_{24}O$, also known as 2,6-di(*tert*-butyl)-*p*-cresol (DBPC), and aromatic amines, eg, *N*-phenyl-α-naphthylamine [90-30-2], $C_{16}H_{13}N$. These are used in turbines, circulation, and hydraulic oils that are intended for extended service at moderate temperatures (see Antioxidants; Antiozonants; Hydrocarbon oxidation).

When the operating temperature exceeds ca 93°C, the catalytic effects of metals become an important factor in promoting oil oxidation. Inhibitors that reduce this catalytic effect usually react with the surfaces of the metals to form protective coatings (see Metal surface treatments). Typical metal deactivators are the zinc dithiophosphates which also decompose hydroperoxides at temperatures above 93°C. Other metal deactivators include triazole and thiodiazole derivatives. Some copper salts intentionally put into lubricants counteract or reduce the catalytic effect of metals.

4.5. Corrosion and Rust Inhibitors

The two most troublesome types of corrosion caused by hydraulic fluids are corrosion by organic acids that develop in the oil and corrosion by contaminants that are picked up and carried by the oil. Corrosion by organic acids can occur in the high strength-bearing inserts used in internal combustion engines. Some of the metals used in these inserts, eg, the lead in copper—lead or lead—bronze, are readily attacked by organic acids in oil. The corrosion inhibitors form a protective film on the bearing surfaces and either may be adsorbed on the metal or chemically bonded to it. The most common additive used for this purpose is zinc dithiophosphate, but other sulfur- and phosphorus-containing materials also are used. Inclusion on highly alkaline materials in engine oil also helps to neutralize strong acids as they form, and thereby greatly reduce corrosion and corrosive wear (see Corrosion and corrosion control).

Rust inhibitors usually are corrosion inhibitors that have a high polar attraction toward metal surfaces and that form a tenacious, continuous film which prevents water from reaching the metal surface. Typical rust inhibitors are amine succinates and alkaline-earth sulfonates. Rust inhibitors can be used in most types of lubricating oils, but factors of selection include possible corrosion of nonferrous metals or formation of emulsions with water. Because rust inhibitors are adsorbed on metal surfaces, an oil can be depleted of its rust inhibitor. In certain cases, it is possible to correct the depletion by adding more inhibitor.

4.6. Antiwear Compounds

Additives are used in many lubricating oils to reduce friction, wear, and scuffing and scoring under boundary lubrication conditions, ie, when full lubricating films cannot be maintained. Two general classes of materials are used to prevent metallic contact.

4.6.1. Mild Wear and Friction-Reducing Compounds

Mild wear and friction-reducing compounds are polar materials, eg, fatty oils, acids, and esters. These compounds, which function under light to moderate loads, are long-chain molecules that form an adsorbed film on metal surfaces where the polar ends of the molecules are attached to the metal. The molecules are projected normal to the surface. Contact is between the projecting ends of the layers of molecules on the opposing surfaces. Friction is reduced and the surfaces move more freely relative to each other. Wear is reduced under mild sliding conditions, but under severe sliding conditions the layers of molecules can be rubbed off. Zinc dialkyl dithiophosphates are a family of friction-reducing compounds for antiwear hydraulic oils. The friction- and wear-reducing mechanism is quite complex.

4.6.2. Extreme Pressure Compounds

At high temperatures or under heavy loads where severe sliding conditions exist, extreme pressure (EP) additives are required to reduce friction, control wear, and prevent severe surface damage. These materials function by reacting with the sliding metal surfaces to form oil-insoluble surface films (11). The sliding process can lead to some film removal, but replacement by further chemical reaction is rapid so that the loss of metal is extremely low. This process gradually depletes the amount of EP additive available in the oil. The severity of the sliding conditions and the additive-metal reactivity dictates which EP additives are required for maximum effectiveness. The optimum reactivity occurs when the additives minimize the adhesive or metallic wear but prevent appreciable corrosive or chemical wear. Additives that are too reactive form thick surface films which have less resistance to attrition, and thus some metal is lost by the sliding action. Because the chemical reaction is greatest on the asperities where contact is made and localized temperatures are highest, EP additives lead to polishing of the surfaces. Consequently, the load is distributed uniformly over a greater contact area which allows for a reduction in sliding severity, more effective lubrication, and reduced wear.

Extreme pressure agents usually contain sulfur, chlorine, or phosphorus, either alone or in combination. Sulfur compounds (qv), sometimes with chlorine or phosphorus compounds (qv), are used in many metal-cutting fluids whereas sulfur—phosphorus combinations are used in industrial gear lubricants. In some cases, borates are used in automotive gear lubricants (see Boron oxides, boric acid, and borates). These materials provide excellent protection against gear-tooth scuffing and are characterized by good oxidation stability, low corrosivity, seal compatibility, and low friction.

5. Properties

Hydraulic fluid functions include transmitting pressure and energy; sealing close-clearance parts against leakage; minimizing wear and friction in bearings and between sliding surfaces in pumps (qv), valves, cylinders, etc; removing heat; flushing away dirt, wear particles, etc; and protecting surfaces against rusting. The hydraulic fluid properties that are used to characterize a suitable product and ASTM test designations are

Property	ASTM test designation
specific gravity	D1298
pour point	D97
flash point	D92
kinematic viscosity	D445
viscosity index	D2270
color, ASTM	D1500
acid number	D664 or 974
rust inhibition	D665
foaming characteristics	D892
oxidation stability	D943
hydrolytic stability	D2619
lubricity testing	
four-ball method	D2266
vane pump wear test	D2882
FZG method	D5182
emulsion characteristics	D1401
water content	D1744

6. Environmental Aspects

Developments in hydraulic fluids are driven by environmental concerns including disposal of waste, waste minimization, biotoxicity, effects on human health, and the ecology.

Used oil disposal trends include waste minimization such as by reclaiming used fluid on site, as well as recycling of mineral oil lubricants instead of disposing by incineration. The recycling effort involves a system where spent mineral oils are collected then shipped to specialty refineries where the materials are distilled, hydrofinished, and re-refined into fresh base stocks. These re-refined materials are virtually identical to virgin feedstocks.

Human and environmental welfare for lubricants and their use is addressed in Material Safety Data Sheets (MSDS). These MSDS address toxicology and health concerns based on the components in the lubricant as well as indicating the proper response in case of a spill. Environmental hazards of the lubricant are covered on European and Japanese MSDS as shown in Table 5.

Table 5. MSDS Environmental Hazard Risk Phrases*[a]*

Risk code	Risk phrase	LC_{50},[b] mg/L
R50	very toxic to aquatic organisms	< 1
R51	toxic to aquatic organisms	1–10
R52	harmful to aquatic organisms	10–100
R53	may cause long-term adverse effects in the aquatic environment	[c]

[a] Ref. 12.
[b] LC_{50} is the concentration in water that kills 50% of the organisms.
[c] Nonbiodegradable, potential bioaccumulator.

Changes in fluid compositions include the reduction and removal of zinc from hydraulic fluids. Zinc-free antiwear hydraulic fluids, which may be ashless and free of phenol, were developed to meet wastewater treatment regulations for industrial sites by reducing the discharge of heavy metals and phenol into waterways.

Vegetable and seed oils as well as some synthetic base stocks present a new class of biodegradable base stocks. These fluids (10) have excellent biodegradation properties as measured by criteria developed by the Environmental Protection Agency (EPA) or Organization of Economic Cooperation and Development (OECD). OECD 301 and EPA 560/6-82-003 measure the biodegradation of lubricants. These tests were developed to measure the degradation of oil, especially two-cycle oil, on waterways. Aquatic toxicity criteria toward fish is also found to be acceptable for this class of fluids as measured by EPA 560/6-82-002 and OECD 203:1–12.

Biodegradable hydraulic fluids are typically made from canola oil (rapeseed oil) or sunflower oil and contain performance additives for antiwear, demulsibility, etc (see Soybeans and other oilseeds). For this class of lubricants care must be taken that the fluid be kept sterile in use, otherwise the fluid may biodegrade in service. The degradation results in rancid fluids and inoperable hydraulic systems which requires extensive cleaning measures.

7. Economic Aspects

Hydraulic fluids are the second largest use of lubricants for automotive and industrial markets. Estimates for 1992 are that 1.089×10^9 L(81×10^6 gal) of hydraulic fluids were sold out of 8.9×10^9 L(2.3×10^9 gal) of total industrial lubricating fluids. The world market is shown in Table 6. Most hydraulic fluids were mineral oil-based products. The remainder represented principally fire-resistant hydraulic fluids and synthetic-based lubricants.

7.1. Petroleum-Based Fluids

The usage and pricing of mineral oil-based hydraulic fluids formulated for use as petroleum-based hydraulic fluids are given in Table 7. The main suppliers of petroleum-based hydraulic fluids in the United States are Amoco, Chevron, Citgo, Exxon, Mobil, Shell, Texaco, and Unocal (14). These eight companies supply about 62% of the hydraulic fluids in the United States. Over 80 other companies which supply general purpose hydraulic

Table 6. Geographical Marketing of Hydraulic Fluids[a]

Geographical area	Sales, %	
	Hydraulic fluids	Industrial lubes[b]
North America	29	26
Western Europe	22	27
Central and Eastern Europe	26	20
Far and Middle East	23	27

[a] Ref. 3.
[b] South America and Africa also have about 4% of the industrial lubricant market.

oils are listed in the Oil Daily's 1992 *Annual Lubricant Buyer's Directory.* Outside the United States, the main suppliers are British Petroleum, Exxon, Mobil, Shell, and Texaco.

Table 7. Mineral Oil-Based Hydraulic Fluids

Type	1992	
	Usage, %	Price,[a] \$/L
antiwear fluids		
premium	58	0.90
premium high VI	9	1.12
rust and oxidation inhibited fluids	15	0.93
all other, including synthetic fluids	18	
Total	*100.0*	

[a] Commercial posted price approximated for drum lots in the United States.

The consumer industries involved and the market share of hydraulic fluids used therein include the following (13):

Industry	Hydraulic fluid market, %
manufacturing (machining)	13
mining	22
construction (transportation)	21
chemicals	7
basic metals	14
miscellaneous	23
Total	*100*

In 1992 U.S. lubricant sales exceeded 8.5×10^6 m^3. The total 1992 U.S. automotive lubricant sales and general industrial sales are given in Tables 8 and 9, respectively (15). The largest industrial segments using hydraulics are mining and construction.

7.2. Fire-Resistant Fluids

The total 1992 usage of fire-resistant fluids amounted to over 151,000 m^3 (4×10^7 gal) worldwide and includes the four principal categories shown in Table 10. The principal suppliers of fire-resistant fluids are listed in Table 11.

Except for fire-resistant fluids, synthetic lubricants have not captured a significant portion of the general lubricant or hydraulic markets, primarily because the cost is two to four times that of other premium lubricants. However, development of satisfactorily formulated products continues.

Table 8. Total U.S. Automotive Lubricant Sales, 10^3 m^3[a,b]

Type	1978	1992
SAE J-183a, engine oils		
monograded	2408	936
multigraded	1720	3106
subtotal	*4128*	*4042*
non SAE J-183a, engine oils		
aircraft	65	34
gasoline-fueled two stroke	55	58
subtotal	*121*	*92*
transmission and hydraulic fluids		
automatic transmission	575	515
universal tractor	155	212
energy/shock absorber, power-steering	51	45
other (manual transmission, etc)	41	11
subtotal	*822*	*783*
gear lubricants		
GL-4 or less	24	28
GL-5 and 6	147	144
subtotal	*171*	*172*
Total	*5243*[c]	*5089*[c]

[a] Ref. 15.
[b] To convert m^3 to U.S. gal, multiply by 264.
[c] Automotive grease is not included.

8. Specifications and Standards

The bulk of hydraulic fluids is specified and purchased on bid. Specifications and approval lists are issued by some manufacturers of hydraulic pumps and system components that require lubrication as well as power for control signal transmission. U.S. government military specifications for hydraulic fluids are listed in Table 12, and ASTM tests that are applicable to hydraulic fluids include the following:

Type and title of test	ASTM number
antiwear properties	
preliminary examination of hydraulic fluids	D2271
vane-pump testing of petroleum hydraulic fluids	D2882
evaluation of scuffing load capacity of oils by FZG	D5182
hydraulic fluid stability	
thermal stability of hydraulic fluids	D2160
hydrolytic stability of hydraulic fluids	D2619
deposition tendencies of liquids in thin film and vapors	D3711
corrosiveness/oxidation stability of hydraulic oils/aircraft lubricants	D4636
fire-resistant tendencies	
flash and fire points by Cleveland open cup	D92
linear flame propagation rate	D5306

Some U.S. governmental lubricant requirements for nontactical equipment is now acquired as Commercial Item Descriptions (CID), rather than against specific military numbers. A new classification system for shear-stable, high VI hydraulic fluids was balloted by ASTM in 1994.

Table 9. Total U.S. General Industrial Sales, 10^3 m^3[a,b]

Type	1978	1992
General industrial lubricants		
hydraulic oils	888	759
fire-resistant fluids		50
gear oils	191	124
turbine/circulation oils	317	186
refrigeration oils	38	14
way oils	29	31
compressor oils	23	19
rock-drill air tools	19	11
all others	142	89
other unspecified	13	16
subtotal	*1661*	*1299*
Industrial engine oils		
railroad diesel	194	108
marine	134	218
natural gas	157	174
subtotal	*486*	*500*
Metalworking oils		
metal-removing	242	123
metal-forming	67	55
metal-treating	28	20
metal-protecting	32	11
all other specified	8	13
unspecified	40	88
subtotal	*418*	*310*
Process oils		
electrical oils	390	250
rubber	304	334
white oils[c]	157	144
paraffinic	218	154
cycloparaffinic	257	116
other, specified	0	252
subtotal	*1326*	*1250*
Total general industrial lubes	*3890*	*3445*

[a] Ref 15.
[b] To convert m^3 to U.S. gal, multiply by 264.
[c] Does not include all production of white oils.

9. Uses

Hydraulic actuation is applied to machine tools, presses, draw benches, jacks, and elevators as well as to die-casting, plastic-molding, welding, coal-mining, and tube-reducing machines. Hydraulic loading is used for pressure, sugar-mill, and paper-machine press rolls, and calender stacks. The hydraulic press shown in Figure 3 is used for a wide variety of metalworking operations, including drawing, forging, straightening, cupping, embossing, and coining. The lifting and tilting mechanism of forklift trucks also are hydraulically operated (2).

Table 10. Type of Fire-Resistant Fluid

Fluid			
Classification	Type	Usage, %	Price, $/L
HF-A	high water-base fluids	22	1.06
HF-B	water-in-oil emulsions	32	1.00
HF-C	water–glycol solutions	26	1.85
HF-D	water-free chemical fluids	20	4.00
	Total	*100*	

Table 11. Fire-Resistant Fluid Suppliers

	Suppliers	
Fluid type	United States	Other countries
HF-A	DuraChem; Houghton; Mobil; Quaker; Sun; Texaco; Unocal	Aral; British Petroleum; Century; Exxon, Houghton; Mobil; Shell
HF-B	Conoco; Houghton; Hulbert; Mobil; Shell; Sun; Unocal	Century; Houghton; Mobil; Quaker; Shell
HF-C	Citgo; DuraChem; Houghton; Mobil; Nalco; Union Carbide; Unocal	British Petroleum; Houghton; Mobil; Union Carbide
HF-D	Akzo; Chevron; FMC; Houghton; Mobil Monsanto; Quaker	British Petroleum; Fina; Houghton; Mobil; Monsanto

Table 12. Hydraulic Fluids for Military Usage

Type of fluid or use	Viscosity	Specification number
arctic low pour hydraulic fluid	ISO VG 15	MIL-H-5606-F
hydraulic, steam turbine	ca ISO VG 68/100	MIL-H-17331-H
hydraulic and light turbine lubricating oil	ISO VG 32, 46, and 68 specified	MIL-H-17672-D
fire-resistant hydraulic fluid	ca ISO VG 46	MIL-H-19457-D
catapult hydraulic fluid	ca ISO VG 46	MIL-H-22072-C
high quality rust and oxidation inhibited oil	ISO VG 32, 46, 68, and 150 specified	MIL-H-46001-C
synthetic hydrocarbon, fire-resistant aircraft fluid	ISO VG 15	MIL-H-83282-C

Load capacities are 0.45–45 t, and operating fluid pressures are from 10.3–17.2 MPa (1500–2500 psi). In plants where forklift trucks must pass near molten metal, open flames, or other sources of ignition, there is a trend toward the use of fire-resistant fluids in the hydraulic systems. Hydraulic actuation also provides the required force as well as ease of control and adjustment of speed that is involved in broaching (2). However, the cost of hydrobroaches and work-holding fixtures limits hydrobroaching to mass-production where a large number of identical parts are machined.

Positive, adjustable-speed hydraulic transmissions are used for driving paper (qv) mills, wire-rope machines, and printing presses (see Printing processes). These transmissions are used on ships for steering gears, hoisting and mooring equipment, and, in the case of naval vessels, to elevate and train guns. Numerous other applications of hydraulics include mechanisms for tilting ladles and operating clamps, brakes, valves, furnace doors, and loading platforms. There are also many hydraulic applications in aircraft, automobiles, trucks, contractor, and farm equipment.

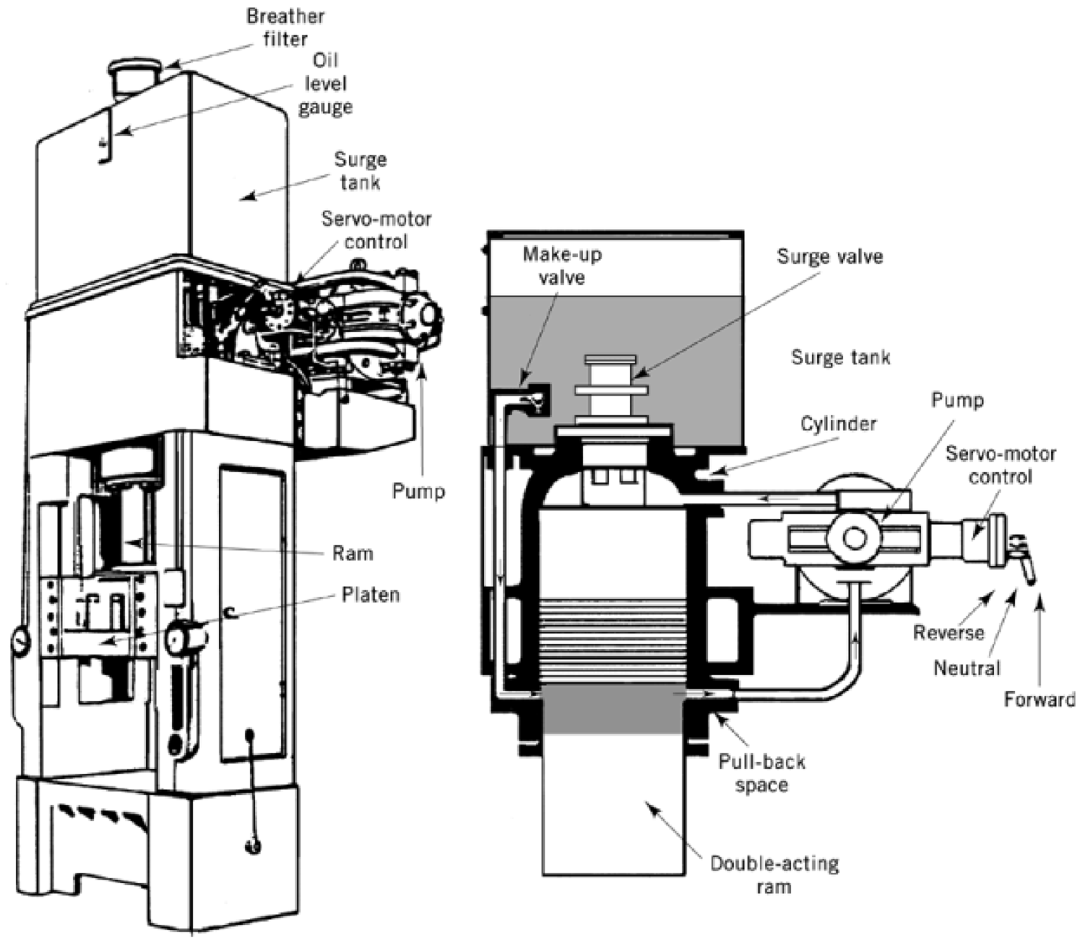


Fig. 3. Hydraulic press.

9.1. Hydrostatic Transmissions

The most recent use of hydraulic power has been in hydrostatic transmissions which are used in many self-propelled harvesting machines and garden tractors and in large tractors and construction machines. Applications in trucks for highway operation also are being developed. No clutch is used and no gear shifting is involved, thus this type of transmission could be called automatic, but in all other respects the hydrostatic transmission has no similarity to the hydrokinetic automatic transmission (16).

The hydrokinetic transmission transfers power from the engine to the gear box by first converting it into kinetic energy of a fluid in the pump. The kinetic energy in the fluid is converted back to mechanical energy in the turbine. In the hydrostatic system, engine power is converted into static pressure of a fluid in the pump, and the static pressure acts on a hydraulic motor to produce the output. Although the fluid moves through the closed circuit between the pump and motor, energy is transferred primarily by the static pressure rather than by the kinetic energy of the moving fluid. The relatively incompressible fluid acts like a solid link between the pump and motor.

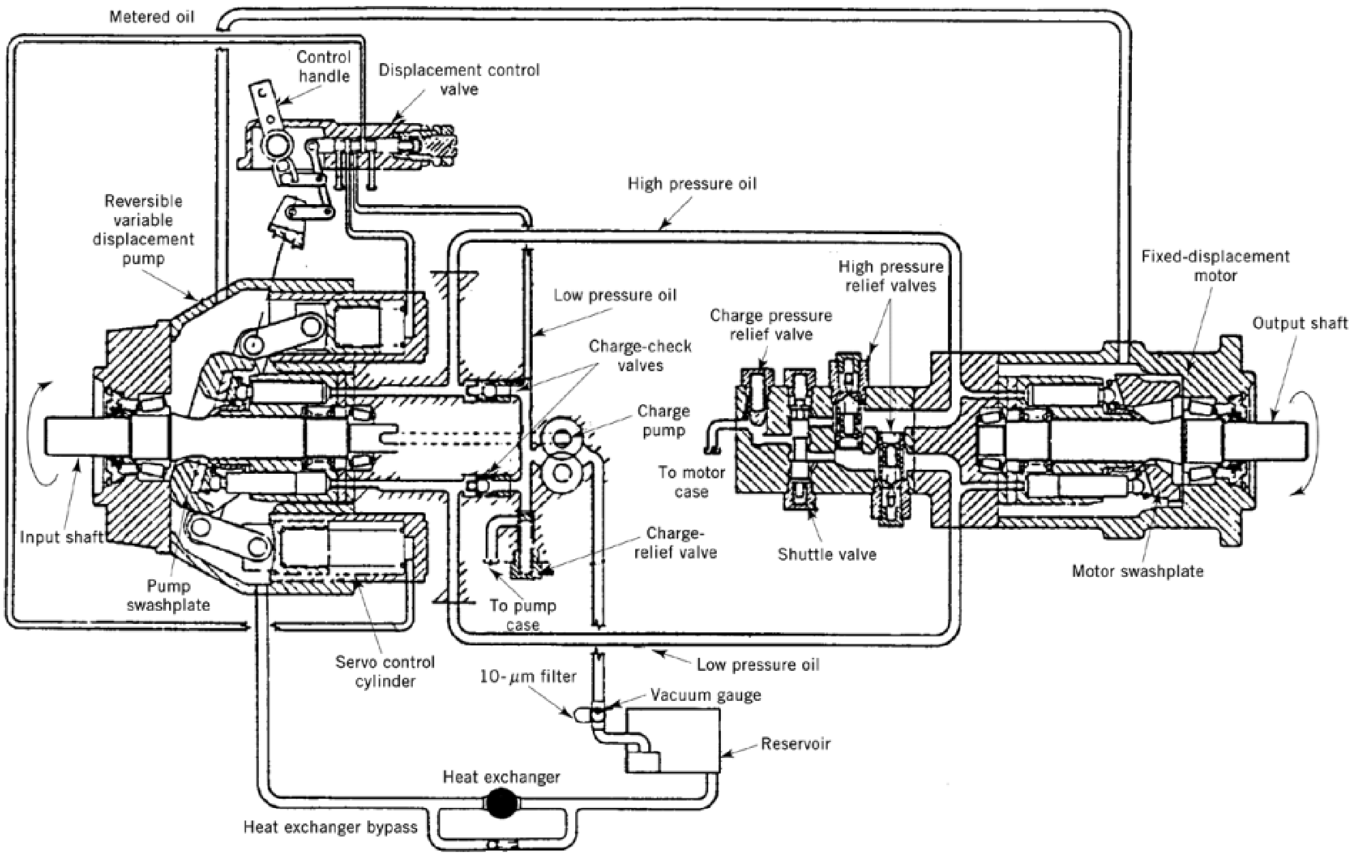


Fig. 4. Hydraulic-drive schematic diagram.

The motor in a hydrostatic system can be any type of positive displacement hydraulic motor. Axial piston motors usually are used for large drives and, in some cases, for small drives. Gear and radial piston motors are used for low power drives; the motor usually is a fixed-displacement type. The direction of rotation is dependent on the direction of flow to the pump in the closed loop circuit. In addition to the pump and motor, connecting lines, relief valves, and a charge pump are required. The connecting lines may be passages where the pump and motor are in the same housing, or may be hoses where the motor is mounted away from the pump. The charge pump provides initial pressurization of the motor and replaces any fluid lost due to internal leakage. On small tractors it may also be used to supply fluid for remote hydraulic cylinders (16). A typical small tractor schematic diagram is shown in Figure 4. The low pressure make-up pump also is used to supply auxiliary hydraulic units. The drive system consists of a variable volume pump with a fixed displacement motor. Fluid is drawn through a strainer from the reservoir and excess fluid that is not required to charge the main pump flows through the filter back to the reservoir.

Hydrostatic drives allow for selection of any travel speed up to the maximum without a concurrent variance in engine speed. The engine can be operated at the governed speed to provide proper operating speeds for auxiliary elements, eg, the threshing section of a combine. A full range of travel speeds is available to adjust to terrain or crop conditions. Industrial applications for hydraulic systems and hydrostatic transmissions include the following (16):

Aircraft	Farm	Construction	Industrial
aircraft controls	tractors	road rollers and compactors	machine tools
constant speed alternator drives	combines, corn pickers	asphalt spreading and paving machines	mining, locomotives and power cranes
ground support equipment	cotton pickers, baler, miscellaneous fruit and vegetable harvesters	road graders, scrapers, front-end loaders, back hoes, trencher and ditching equipment, concrete mixer, truck cranes, aggregate plants, drilling rigs	lift and shop trucks, loggers chain

9.2. Electrorheological Fluids

Electrorheological fluids are a newer category of hydraulic fluids being actively pursued for use in shock absorbers. An electric field causes the fluid to thicken.

9.3. Fire-Resistant Hydraulic Fluids

Fire-resistant hydraulic fluids are used where the fluid could spray or drip from a break or leak onto a source of ignition, eg, a pot of molten metal or a gas flame (17). Conditions such as these exist in die-casting machines or in presses located near furnaces. Specific tests for fire resistance are conducted by Factory Mutual in the United States.

High water-content fluids are used in some hydraulic systems where work-stroke speeds are very low, eg, large freight elevators and large forging and extrusion presses. Pressures in these systems may be from 13.8–20.7 MPa (2000–3000 psi). Vertical in-line pumps with packed plungers and special axial—piston pumps are used with these fluids.

Water-in-oil emulsions are used as fire-resistant hydraulic fluids to replace petroleum hydraulic fluids in general industry, coal mines, and rolling mills where a fire hazard exists (1).

9.4. Synthetic Lubricants

Some of the primary applications for synthetic lubricants include the following (6):

Field of service	Synthetic fluids used
industrial	
circulating oils	polyglycols, synthetic hydrocarbon fluid (SHF), organic esters
gear lubricants	polyglycols, SHF
hydraulic fluids (fire-resistant)	phosphate esters, polyglycols
compressor oils	polyglycols, organic esters, SHF
gas turbine oils	SHF, organic esters
greases	SHF
automotive	
passenger car engine oils	SHF, organic esters
commercial engine oils	SHF, organic esters
gear lubricants	SHF
brake fluids	polyglycols
aviation	
gas turbines	organic esters
hydraulic fluids	SHF, phosphate esters, silicones
greases	silicones, organic esters, SHF

Olefin oligomers are used widely as automotive lubricants. They often are combined with some of the organic esters as base fluids in engine oils, gear oils, and hydraulic fluids, eg, for equipment intended for operation in extremely cold climates, and for premium oils, eg, for the service station market in temperate climates.

Alkylated aromatics are used as the base fluid in engine oils, gear oils, hydraulic fluids, and greases in subzero applications. They also are used as the base fluid in power transmission fluids and gas turbine, air compressor, and refrigeration compressor lubricants.

Polybutenes are used as electrical insulating oils, eg, as cable oils in high voltage underground cables, as impregnants to insulate paper for cables, as liquid dielectrics, and as impregnants for capacitors. Significant volumes are used as lubricants for rolling, drawing, and extrusion of aluminum before the aluminum is to be annealed. Other applications include gas compressor lubrication, open gear oils, food-grade lubricants, and as carriers for solid lubricants (such as chain lubricants).

Cycloaliphatics are used in stepless, variable-speed drives in which the torque is transmitted from the driving member to the driven member by the resistance to shear of the lubricating fluid. The high traction coefficients of the cycloaliphatics permit higher power ratings than conventional lubricants. Cycloaliphatics also are used in rolling element bearings to prevent skidding of the rolling elements.

Dibasic acid esters and polyol esters are used as the bases in all aircraft jet-engine lubricants. They also are employed in aircraft greases that are subjected to wide temperature ranges.

Polyglycol application depend on whether the water-soluble or water-insoluble types are used. The largest volume application of the water-soluble polyglycols is as hydraulic brake fluids. Other applications are in metalworking lubricants, where they can be removed by water flushing or burning, and in fire-resistant hydraulic fluids. In the latter application, the polyglycol is mixed with water, which provides the fire resistance. Some water-soluble glycols are used in quenching fluids because they become insoluble in water upon heating. Water-soluble polyglycols are also used in the preparation of water-diluted lubricants for rubber bearings and joints. Water-insoluble polyglycols are used as heat-transfer fluids and as the base fluid in certain industrial hydraulic fluids and in high temperature and bearing oils (see Heat-exchange technology, heat-transfer media other than water).

Phosphate esters are used predominantly in fire-resistant fluids. Hydraulic fluids for commercial aircraft are based on phosphate esters, as are many industrial fire-resistant hydraulic fluids. The latter are used in electrohydraulic control systems of steam turbines and industrial hydraulic systems where hydraulic fluid leakage might contact a source of ignition. In some cases, they are used in turbine bearing lubrication systems. Considerable quantities of phosphate esters are used as lubricants for compressors (where discharge temperatures are high) to prevent receiver fires which might occur with conventional lubricants. Some quantities are used in greases and miner oil blends are wear and friction reducing additives.

Silicones are used as compressor lubricants and as the base fluids in wide temperature range applications and in high temperature greases. They also are used in specialty greases designed to lubricate elastomeric materials that would be adversely affected by other types of lubricants. Silicones are used in specialty hydraulic fluids for liquid springs and torsion dampers where their high compressibility and minimal change in viscosity with temperature are beneficial. They also are being developed for use as hydraulic brake fluids.

Halogenated hydrocarbons that are inexpensive sometimes are used alone or in blends with phosphate esters as fire-resistant hydraulic fluids. Other halogenated fluids are used for oxygen-compressor lubricants, lubricants for vacuum pumps that are in contact with corrosive materials, solvent-resistant lubricants, and other lubricant applications where highly corrosive or reactive materials are being handled.

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Related Articles

Lubrication and lubricants; Corrosion and corrosion control; Olefin polymers; Glycols