Chapter 3
Lubricating Oils

3-1. Oil Refining

Most lubricating oils are currently obtained from distillation of crude petroleum. Due to the wide variety of petroleum constituents, it is necessary to separate petroleum into portions (fractions) with roughly the same qualities.

a. General scheme of the refining process. The refining process can be briefly described as follows:

(1) Crudes are segregated and selected depending on the types of hydrocarbons in them.

(2) The selected crudes are distilled to produce fractions. A fraction is a portion of the crude that falls into a specified boiling point range.

(3) Each fraction is processed to remove undesirable components. The processing may include:

- Solvent refining to remove undesirable compounds.
- Solvent dewaxing to remove compounds that form crystalline materials at low temperature.
- Catalytic hydrogenation to eliminate compounds that would easily oxidize.
- Clay percolation to remove polar substances.

(4) The various fractions are blended to obtain a finished product with the specified viscosity. Additives may be introduced to improve desired characteristics. The various types of and uses for additives are discussed in Chapter 7.

b. Separation into fractions. Separation is accomplished by a two-stage process: crude distillation and residuum distillation.

(1) Crude distillation. In the first stage the crude petroleum is mixed with water to dissolve any salt. The resulting brine is separated by settling. The remaining oil is pumped through a tubular furnace where it is partially vaporized. The components that have a low number of carbon atoms vaporize and pass into a fractionating column or tower. As the vapors rise in the column, cooling causes condensation. By controlling the temperature, the volatile components may be separated into fractions that fall within particular boiling point ranges. In general, compounds with the lowest boiling points have the fewest carbon atoms and compounds with the highest boiling points have the greatest number of carbon atoms. This process reduces the number of compounds within each fraction and provides different qualities. The final products derived from this first-stage distillation process are raw gasoline, kerosene, and diesel fuel.

(2) Residuum distillation. The second-stage process involves distilling the portion of the first-stage that did not volatilize. Lubricating oils are obtained from this portion, which is referred to as the residuum. To prevent formation of undesired products, the residuum is distilled under vacuum so it will boil at a lower temperature. Distillation of the residuum produces oils of several boiling point ranges. The higher

the boiling point, the higher the carbon content of the oil molecules in a given range. More importantly, viscosity also varies with the boiling point and the number of carbon atoms in the oil molecules.

c. Impurity removal. Once the oil is separated into fractions, it must be further treated to remove impurities, waxy resins, and asphalt. Oils that have been highly refined are usually referred to as premium grades to distinguish them from grades of lesser quality in the producer's line of products. However, there are no criteria to establish what constitutes premium grade.

3-2. Types of Oil

Oils are generally classified as refined and synthetic. Paraffinic and naphthenic oils are refined from crude oil while synthetic oils are manufactured. Literature on lubrication frequently makes references to long-chain molecules and ring structures in connection with paraffinic and naphthenic oils, respectively. These terms refer to the arrangement of hydrogen and carbon atoms that make up the molecular structure of the oils. Discussion of the chemical structure of oils is beyond the scope of this manual, but the distinguishing characteristics between these oils are noted below.

a. Paraffinic oils. Paraffinic oils are distinguished by a molecular structure composed of long chains of hydrocarbons, i.e., the hydrogen and carbon atoms are linked in a long linear series similar to a chain. Paraffinic oils contain paraffin wax and are the most widely used base stock for lubricating oils. In comparison with naphthenic oils, paraffinic oils have:

- Excellent stability (higher resistance to oxidation).
- Higher pour point.
- Higher viscosity index.
- Low volatility and, consequently, high flash points.
- Low specific gravities.

b. Naphthenic oils. In contrast to paraffinic oils, naphthenic oils are distinguished by a molecular structure composed of “rings” of hydrocarbons, i.e., the hydrogen and carbon atoms are linked in a circular pattern. These oils do not contain wax and behave differently than paraffinic oils. Naphthenic oils have:

- Good stability.
- Lower pour point due to absence of wax.
- Lower viscosity indexes.
- Higher volatility (lower flash point).
- Higher specific gravities.

Naphthenic oils are generally reserved for applications with narrow temperature ranges and where a low pour point is required.

c. Synthetic oils.

(1) Synthetic lubricants are produced from chemical synthesis rather than from the refinement of existing petroleum or vegetable oils. These oils are generally superior to petroleum (mineral) lubricants in most circumstances. Synthetic oils perform better than mineral oils in the following respects:

- Better oxidation stability or resistance.

- Better viscosity index.

- Much lower pour point, as low as -46 °C (-50 °F).

- Lower coefficient of friction.

(2) The advantages offered by synthetic oils are most notable at either very low or very high temperatures. Good oxidation stability and a lower coefficient of friction permits operation at higher temperatures. The better viscosity index and lower pour points permit operation at lower temperatures.

(3) The major disadvantage to synthetic oils is the initial cost, which is approximately three times higher than mineral-based oils. However, the initial premium is usually recovered over the life of the product, which is about three times longer than conventional lubricants. The higher cost makes it inadvisable to use synthetics in oil systems experiencing leakage.

(4) Plant Engineering magazine's "Exclusive Guide to Synthetic Lubricants," which is revised every three years, provides information on selecting and applying these lubricants. Factors to be considered when selecting synthetic oils include pour and flash points; demulsibility; lubricity; rust and corrosion protection; thermal and oxidation stability; antiwear properties; compatibility with seals, paints, and other oils; and compliance with testing and standard requirements. Unlike Plant Engineering magazine's "Chart of Interchangeable Lubricants," it is important to note that synthetic oils are as different from each other as they are from mineral oils. Their performance and applicability to any specific situation depends on the quality of the synthetic base-oil and additive package, and the synthetic oils listed in Plant Engineering are not necessarily interchangeable.

d. Synthetic lubricant categories.

(1) Several major categories of synthetic lubricants are available including:

(a) Synthesized hydrocarbons. Polyalphaolefins and dialkylated benzenes are the most common types. These lubricants provide performance characteristics closest to mineral oils and are compatible with them. Applications include engine and turbine oils, hydraulic fluids, gear and bearing oils, and compressor oils.

(b) Organic esters. Diabasic acid and polyol esters are the most common types. The properties of these oils are easily enhanced through additives. Applications include crankcase oils and compressor lubricants.

(c) Phosphate esters. These oils are suited for fire-resistance applications.

(d) Polyglycols. Applications include gears, bearings, and compressors for hydrocarbon gases.

(e) Silicones. These oils are chemically inert, nontoxic, fire-resistant, and water repellant. They also have low pour points and volatility, good low-temperature fluidity, and good oxidation and thermal stability at high temperatures.

(2) Table 3-1 identifies several synthetic oils and their properties.

3-3. Characteristics of Lubricating Oils

a. Viscosity. Technically, the viscosity of an oil is a measure of the oil's resistance to shear. Viscosity is more commonly known as resistance to flow. If a lubricating oil is considered as a series of fluid layers superimposed on each other, the viscosity of the oil is a measure of the resistance to flow between the individual layers. A high viscosity implies a high resistance to flow while a low viscosity indicates a low resistance to flow. Viscosity varies inversely with temperature. Viscosity is also affected by pressure; higher pressure causes the viscosity to increase, and subsequently the load-carrying capacity of the oil also increases. This property enables use of thin oils to lubricate heavy machinery. The load-carrying capacity also increases as operating speed of the lubricated machinery is increased. Two methods for measuring viscosity are commonly employed: shear and time.

(1) Shear. When viscosity is determined by directly measuring shear stress and shear rate, it is expressed in centipoise (cP) and is referred to as the absolute or dynamic viscosity. In the oil industry, it is more common to use kinematic viscosity, which is the absolute viscosity divided by the density of the oil being tested. Kinematic viscosity is expressed in centistokes (cSt). Viscosity in centistokes is conventionally given at two standard temperatures: 40 °C and 100 °C (104 °F and 212 °F).

(2) Time. Another method used to determine oil viscosity measures the time required for an oil sample to flow through a standard orifice at a standard temperature. Viscosity is then expressed in SUS (Saybolt Universal Seconds). SUS viscosities are also conventionally given at two standard temperatures: 37 °C and 98 °C (100 °F and 210 °F). As previously noted, the units of viscosity can be expressed as centipoise (cP), centistokes (cST), or Saybolt Universal Seconds (SUS), depending on the actual test method used to measure the viscosity.

b. Viscosity index. The viscosity index, commonly designated VI, is an arbitrary numbering scale that indicates the changes in oil viscosity with changes in temperature. Viscosity index can be classified as follows: low VI - below 35; medium VI - 35 to 80; high VI - 80 to 110; very high VI - above 110. A high viscosity index indicates small oil viscosity changes with temperature. A low viscosity index indicates high viscosity changes with temperature. Therefore, a fluid that has a high viscosity index can be expected to undergo very little change in viscosity with temperature extremes and is considered to have a stable viscosity. A fluid with a low viscosity index can be expected to undergo a significant change in viscosity as the temperature fluctuates. For a given temperature range, say -18 to 370°C (0 - 100 °F), the viscosity of one oil may change considerably more than another. An oil with a VI of 95 to 100 would change less than one with a VI of 80. Knowing the viscosity index of an oil is crucial when selecting a lubricant for an application, and is especially critical in extremely hot or cold climates. Failure to use an oil with the proper viscosity index when temperature extremes are expected may result in poor lubrication and equipment failure. Typically, paraffinic oils are rated at 38 °C (100 °F) and naphthenic oils are rated at -18 °C (0 °F). Proper selection of petroleum stocks and additives can produce oils with a very good VI.

Table 3-1
Synthetic Oils

Fluid Property	Di-ester	Typical Phosphate Ester	Inhibited Esters	Typical Methyl Silicone	Typical Phenyl Methyl Silicone	Chlorinated Phenyl Methyl Silicone	Polyglycol (inhibited)	Perfluorinate Polyether
Maximum temperature in absence of oxygen (°C)	250	300	110	220	320	305	260	370
Maximum temperature in presence of oxygen (°C)	210	240	110	180	250	230	200	310
Maximum temperature due to decrease in viscosity (°C)	150	180	100	200	250	280	200	300
Minimum temperature due to increase in viscosity (°C)	-35	-65	-55	-50	-30	-65	-20	-60
Density (g/ml)	0.91	1.01	1.12	0.97	1.06	1.04	1.02	1.88
Viscosity index	145	140	0	200	175	195	160	100-300
Flash point (°C)	230	255	200	310	290	270	180	
Spontaneous ignition temperature	Low	Medium	Very high	High	High	Very high	Medium	Very high
Thermal conductivity (W/M °C)	0.15	0.14	0.13	0.16	0.15	0.15	0.15	
Thermal capacity (J/kg °C)	2,000	1,700	1,600	1,550	1,550	1,550	2,000	
Bulk modulus	Medium	Medium	Medium	Very low	Low	Low	Medium	Low
Boundary lubrication	Good	Good	Very good	Fair, but poor for steel on steel	Fair, but poor for steel on steel	Good	Very good	Poor
Toxicity	Slight	Slight	Some toxicity	Nontoxic	Nontoxic	Nontoxic	Believed to be low	Low
Suitable rubbers	Nitrile, silicone	Silicone	Butyl, EPR	Neoprene, viton	Neoprene, viton	Viton, fluoro-silicone	Nitrile	Many
Effect on plastics	May act as plasticizers		Powerful solvent	Slight, but may leach out plasticizers	Slight, but may leach out plasti-cizers	Slight, but may leach out plasticizers	Generally mild	Mild
Resistance to attack by water	Good	Good	Fair	Very good	Very good	Good	Good	Very good
Resistance to chemicals	Attacked by alkali	Attacked by alkali	Attacked by many chemicals	Attacked by strong alkali	Attacked by strong alkali	Attacked by alkali	Attacked by oxidants	Very good
Effect on metals	Slightly corrosive to Non-ferrous metals	Corrosive to some Non-ferrous metals when hot	Enhanced corrosion in presence of water	Non-corrosive	Non-corrosive	Corrosive in presence of water to ferrous metals	Non-corrosive	Removes oxide films at elevated temperatures
Cost (relative to mineral oil)	4	6	6	15	25	40	4	500

Note: Application data for a variety of synthetic oils are given in this table. The list is not complete, but most readily available synthetic oils are included. The data are generalizations, and no account has been taken of the availability and property variations of different viscosity grades in each chemical type. Reference: Neale, M.J., Lubrication: A Tribology Handbook

(Continued)

Table 3-1 (Continued)

Fluid Property	Chlorinated Diphenyl	Silicate Ester or Disiloxame	Polyphenyl Ether	Fluorocarbon	Mineral Oil (for comparison)	Remark
Maximum temperature in absence of oxygen (°C)	315	300	450	300	200	For esters this temperature will be higher in the absence of metals
Maximum temperature in absence of oxygen (°C)	145	200	320	300	150	This limit is arbitrary. It will be higher if oxygen concentration is low and life is short
Maximum temperature due to decrease in viscosity (°C)	100	240	150	140	200	With external pressurization or low loads this limit will be higher
Minimum temperature due to decrease in viscosity (°C)	-10	-60	0	-50	0 to -50	This limit depends on the power available to overcome the effect of increased viscosity
Density (g/ml)	1.42	1.02	1.19	1.95	0.88	
Viscosity index	-200 to +25	150	-60	-25	0 to 140	A high viscosity index is desirable
Flash point (°C)	180	170	275	None	150 to 200	Above this temperature the vapor of the fluid may be ignited by an open flame
Spontaneous ignition temperature	Very high	Medium	High	Very high	Low	Above this temperature the fluid may ignite without any flame being present
Thermal conductivity (W/m° C)	0.12	0.15	0.14	0.13	0.13	A high thermal conductivity and high thermal capacity are desirable for effective cooling
Thermal capacity (J/kg° C)	1,200	1,700	1,750	1,350	2,000	
Bulk modulus	Medium	Low	Medium	Low	Fairly high	There are four different values of bulk modulus for each fluid but the relative qualities are consistent
Boundary lubrication	Very good	Fair	Fair	Very good	Good	This refers primarily to antiwear properties when some metal contact is occurring
Toxicity	Irritant vapor when hot	Slight	Believed to be low	Nontoxic unless overheated	Slight	Specialist advice should always be taken on toxic hazards
Suitable rubbers	Viton	Viton nitrile, floro-silicone	(None for very high tempera-tures)	Silicone	Nitrile	
Effect on plastics	Powerful solvent	Generally mild	Polyimides satisfactory	Some soften-ing when hot	Generally slight	
Resistance to attack by water	Excellent	Poor	Very good	Excellent	Excellent	This refers to breakdown of the fluid itself and not the effect of water on the system
Resistance to chemicals	Very resistant	Generally poor	Resistant	Resistant but attacked by alkali and amines	Very resistant	
Effect on metals	Some corrosion of copper alloys	Noncorrosive	Noncorrosive	Noncorrosive, but unsafe with aluminum and magnesium	Noncorrosive when pure	
Cost (relative to mineral oil)	10	8	100	300	1	These are rough approximations and vary with quality and supply position

c. Pour point. The pour point is the lowest temperature at which an oil will flow. This property is crucial for oils that must flow at low temperatures. A commonly used rule of thumb when selecting oils is to ensure that the pour point is at least 10 °C (20 °F) lower than the lowest anticipated ambient temperature.

d. Cloud point. The cloud point is the temperature at which dissolved solids in the oil, such as paraffin wax, begin to form and separate from the oil. As the temperature drops, wax crystallizes and becomes visible. Certain oils must be maintained at temperatures above the cloud point to prevent clogging of filters.

e. Flash point and fire point. The flash point is the lowest temperature to which a lubricant must be heated before its vapor, when mixed with air, will ignite but not continue to burn. The fire point is the temperature at which lubricant combustion will be sustained. The flash and fire points are useful in determining a lubricant's volatility and fire resistance. The flash point can be used to determine the transportation and storage temperature requirements for lubricants. Lubricant producers can also use the flash point to detect potential product contamination. A lubricant exhibiting a flash point significantly lower than normal will be suspected of contamination with a volatile product. Products with a flash point less than 38 °C (100 °F) will usually require special precautions for safe handling. The fire point for a lubricant is usually 8 to 10 percent above the flash point. The flash point and fire point should not be confused with the auto-ignition temperature of a lubricant, which is the temperature at which a lubricant will ignite spontaneously without an external ignition source.

f. Acid number or neutralization number. The acid or neutralization number is a measure of the amount of potassium hydroxide required to neutralize the acid contained in a lubricant. Acids are formed as oils oxidize with age and service. The acid number for an oil sample is indicative of the age of the oil and can be used to determine when the oil must be changed.

3-4 Oil Classifications and Grading Systems

a. Professional societies classify oils by viscosity ranges or grades. The most common systems are those of the SAE (Society of Automotive Engineers), the AGMA (American Gear Manufacturers Association), the ISO (International Standards Organization), and the ASTM (American Society for Testing and Materials). Other systems are used in special circumstances.

b. The variety of grading systems used in the lubrication industry can be confusing. A specification giving the type of oil to be used might identify an oil in terms of its AGMA grade, for example, but an oil producer may give the viscosity in terms of cSt or SUS. Conversion charts between the various grading systems are readily available from lubricant suppliers. Conversion between cSt and SUS viscosities at standard temperatures can also be obtained from ASTM D 2161.