40 Lubrication

Original by BP Oil UK Ltd
Revised by Eric Sloman
Consultant

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40.1 Introduction

This chapter examines the need for lubrication and the types of lubricant available. Various applications are considered, including engines gears, hydraulic equipment, machine tools, metal cutting and working fluids, compressors, turbines and electrical oils. The care of lubricants on-site, application of planned lubrication and inclusion within overall maintenance management are also examined.

The plant engineer's objective must be to ensure that plant operates at a profit. If overall efficiency of operation is to be achieved, and the working costs of plant kept within acceptable bounds, time must be set aside for the control and application of lubrication. The evolution of lubricants and their application, has continued ever since the beginning of the Industrial Revolution, and as the pattern of industry becomes increasingly more complex, the standard of performance of lubricants becomes progressively more important.

40.2 Lubrication – the added value

All machines depend for their accuracy on the strength of their component parts, their bearings and on the type and efficiency of their lubrication systems. Many machine bearings are subjected to extremely heavy shock loads, or intermittent loads, or exposure to unfavourable environmental conditions, yet in spite of this they must always maintain their setting accuracy.

Accuracy and reproducibility are of vital importance to industry. Quite apart from the effect of these factors on the final product, several plant items are frequently links in a continuous chain of production processes. A sizing error in one machine, for example, could overstress and damage the succeeding machinery. Similarly, an error in a press may increase stress on the tool and could necessitate an additional operation to remove excessive 'flash'. Wear in a material preparation unit could allow oversize material to be passed to a moulding machine, creating an overload situation with consequent damage.

The reduction of friction is only one of the functions of a lubricant. It must remove heat (often in large amounts), protect bearings from damage and preserve the working accuracy and alignment of the structure. It must also protect bearings, gears and other parts against corrosion, and must itself be non-corrosive. Sometimes it may be required to seal shafts and bearings against moisture and the ingress of contaminating particles. The lubricant must be of the correct viscosity for its application and may need additives to meet specification requirements. It must also be non-toxic, and both chemically and physically stable.

Lubrication plays a vital role in the operation of industrial plant. For example, in a heavy rolling mill the lubrication system, though mostly out of sight in the oil cellar, may have a capacity of many thousands of litres and exceed in bulk the mill itself. Lubrication systems of this size and complexity are usually fully automatic, with many interlocks and other safety features. Even with the smallest machines, automatic lubrication is becoming more popular. Where an automatic system would be impracticable or uneconomical, as with many older or less complex machines, it is nevertheless important that lubrication be carried out in accordance with a planned schedule.

It can be seen therefore that heavy demands are made on the plant concerned, and hence on the lubricants required for its efficient operation. The importance of the correct selection and application of lubricants, in the correct amount and at the right time, will be readily appreciated. The cost of providing high-quality lubrication is negligible compared with the material return it will bring in terms of longer working life, higher output of work and reduced maintenance costs.

40.3 Why a lubricant?

When the surfaces of two solid bodies are in contact a certain amount of force must be applied to one of them if relative motion is to occur. Taking a simple example, if a dry steel block is resting on a dry steel surface, relative sliding motion will not start until a force approximately equal to one fifth the weight of the steel block is applied. In general, the static friction between any two surfaces of similar materials is of this magnitude, and is expressed as a coefficient of friction of 0.2. As soon as the initial resistance is overcome, a very much smaller force will keep the slider moving at uniform velocity. This second frictional condition is called dynamic friction. In every bearing or sliding surface, in every type of machine, these two coefficients are of vital importance. Static friction sets the force required to start the machine and dynamic friction absorbs power which must be paid for in terms of fuel consumed. Also, friction resistance of unlubricated surfaces causes heating, rapid wear and even, under severe conditions, actual welding together of the two surfaces.

Lubrication, in the generally accepted sense of the word, means keeping moving surfaces completely separated by means of a layer of some liquid. When this is satisfactorily achieved the frictional resistance no longer depends on the solid surfaces but solely on the internal friction of the liquid which, in turn, is directly related to its viscosity. The more viscous the fluid, the greater the resistance, but this is never comparable with that existing between unlubricated surfaces.

40.3.1 Types of lubrication

Lubrication exists in one of three conditions:

1. Boundary lubrication
2. Elastohydrodynamic lubrication
3. Full fluid-film lubrication

Boundary lubrication is perhaps best defined as the lubrication of surfaces by fluid films so thin that the friction coefficient is affected by both the type of lubricant and the nature of the surface, and is largely independent of viscosity. A fluid lubricant introduced between two surfaces may spread to a microscopically thin film that reduces the sliding friction between the surfaces. The peaks of the high spots may touch, but interlocking occurs only to a limited extent and frictional resistance will be relatively low.

A variety of chemical additives can be incorporated in lubricating oils to improve their properties under boundary lubrication conditions. Some of these additives react with the surfaces to product an extremely thin layer of solid lubricant, which helps to separate the surfaces and prevent seizure. Others improve the resistance of the oil film to the effect of pressure.

Elastohydrodynamic lubrication provides the answer to why many mechanisms operate under conditions which are beyond the limits forecast by theory. It was previously thought that increasing pressure reduced oil film thickness until the asperities broke through, causing metal-to-metal contact. Research has shown, however, that the effect on mineral oil of high contact pressure is a large increase in the viscosity of the lubricant. This viscosity increase combined with the elasticity of the metal causes the oil film to act like a thin solid film, thus preventing metal-to-metal contact.

Full fluid-film lubrication can be illustrated by reference to the conditions existing in a properly designed plain bearing. If the two bearing surfaces can be separated completely by a fluid film, frictional wear of the surface is virtually eliminated. Resistance to motion will be reduced to a level governed largely by the viscosity of the lubricating fluid.

To generate a lubricating film within a bearing, the opposed surfaces must be forced apart by pressure generated within the fluid film. One way is to introduce the fluid under sufficient pressure at the point of maximum loading, but this hydrostatic method, although equally effective at all speeds, needs considerable power and is consequently to be avoided whenever a satisfactory alternative exists.

Above a certain critical speed, which depends mainly on the size and loading of the bearing and the viscosity of the lubricant, hydrodynamic forces are set up that part the surfaces and permit full fluid-film lubrication. At rest, the fluid film has been squeezed from beneath the shaft, leaving only an absorbed film on the contacting surfaces. As the shaft starts to revolve, friction between the journal and the bearing bore causes the shaft to climb up the inside of the bearing until torque, together with the increased thickness of lubricant film, overcomes frictional resistance and the shaft starts to slip at the point of contact. The rotating shaft then takes up its equilibrium position, where it is supported on a fluid film drawn beneath it by viscous friction (see Figure 40.1).

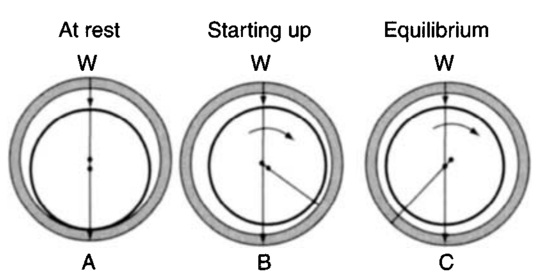

Figure 40.1 Journal positions during start-up while a hydrodynamic oil 'wedge' is being established

40.4 Physical characteristics of oils and greases

Reference will be made to the physical characteristics of lubricants as they affect their selection for various applications. These terms are well known to the lubricant supplier but are not always fully understood by the user. Brief descriptions of these characteristics are therefore given so that their significance may be appreciated.

40.4.1 Viscosity

This is the most important physical property of a lubricating oil; it is a measure of its internal friction or resistance to flow. In simple terms, it provides a measure of the thickness of a lubricating oil at a given temperature; the higher the viscosity, the thicker the oil. Accurate determination of viscosity involves measuring the rate of flow in capillary tubes, the unit of measurement being the centistoke (cSt). As oils become thinner on heating and thicker on cooling a viscosity figure must always be accompanied by the temperature at which it was determined.

The number of commercial viscosity systems can be confusing, and as kinematic viscometers are much more sensitive and consistent, there is a growing tendency to quote kinematic viscosities. The International Standards Organization (ISO) uses kinematic viscosity in its viscosity grade classification (Table 40.1). These ISO grade numbers are used by most oil companies in their industrial lubricant nomenclature. This provides the user with a simple verification of conformity regarding viscosity between plant manufacturer and oil supplier recommendations and also in the monitoring of correct oil usage on his plant.

Table 40.1 ISO viscosity grade chart

ISO viscosity grade	*Mid-point kinematic viscosity*	*Kinematic viscosity limits cSt at 40°C (104°F)*	
		min.	*max.*
2	2.2	1.98	2.42
3	3.2	2.88	3.52
5	4.6	4.14	5.06
7	6.8	6.12	7.48
10	10	9.00	11.0
15	15	13.5	16.5
22	22	19.8	24.2
32	32	28.8	35.2
46	46	41.4	50.6
68	68	61.2	74.8
100	100	90.0	110
150	150	135	165
220	220	198	242
320	320	288	352
460	460	414	506
680	680	612	748
1000	1000	900	1100
1500	1500	1350	1650

40.4.2 Viscosity Index (VI)

This is a way of expressing the rate of change of viscosity with temperature. All oils become less viscous as the temperature increases. The rate of change of viscosity varies with different oils and is mainly dependent on the type of crude from which the oil is derived and the refining method. The higher the VI figure, the lower is the variation in viscosity relative to temperature. The VI of an oil is an important property in applications where the operating temperature is subject to considerable change.

40.4.3 Pour point

This is a rough measure of a limiting viscosity. It is the temperature 2.5°C above that at which the oil ceases to flow when the vessel in which it has been cooled is held horizontally for 5 s. The pour point is a guide to behaviour and care should always be taken that operating temperatures are above the figure specified by the oil manufacturer as the pour point of a given oil.

40.4.4 Flash point

The flash point is an oil is the temperature at which it gives off, under specified conditions, sufficient vapour to form a flammable mixture with air. This is very different from the temperature of spontaneous combustion. The test is an empirical one and the result depends upon the instrument used and the prescribed conditions. For example, the flash point may be 'closed' or 'open', depending on whether the test apparatus has a lid or not. As far as lubricating oils are concerned, the test is of limited significance, although it can be indicative of contamination (for example, the dilution of crankcase oil by fuel).

40.4.5 Penetration of grease

The most important physical property of a lubricating grease is its consistency, which is analogous to the viscosity of a liquid. This is determined by an indentation test in which a weighted metal cone is allowed to sink into the grease for a specified time. The depth to which the cone penetrates, in tenths of a millimetre, is a measure of the consistency. There is a widely accepted scale, that of the American National Lubricating Grease Institute (NLGI), that relates penetration to a consistency number (Figure 40.2).

The penetration test is used mainly to control manufacture and to classify greases and is, within limits, a guide to selection. Penetrations are often qualified by the terms 'worked' and 'unworked'. As greases are thixotropic, that is, they soften as a result of shear but harden again after shearing has stopped, the worked penetration for a particular grease may be appreciably greater than the unworked penetration. The difference between these two figures may be a useful guide to the selection of greases for operating conditions that involve much churning – as small a difference as possible being desirable (see Table 40.2).

Figure 40.2 Grease penetrometer

Table 40.2 NLGI consistency classification for greases

NLGI number	*ASTM worked penetration at 77°F*
000	455–475
00	400–435
0	355–385
1	310–340
2	265–295
3	220–250
4	175–205
5	130–160
6	85–115

40.4.6 Drop point of grease

The drop point of a grease is an indication of change from a soft solid to a viscous fluid; its value depends completely on the conditions of test, particularly the rate of heating. The grease sample, which is held in a small metal cup with an orifice, is heated at a predetermined rate. The drop point is the temperature at which a drop of the sample falls from the cup.

The drop point is of limited significant as far as the user is concerned, for it gives no indication of the condition of the grease at lower temperatures, or of change in consistency or structure with heat. It is a very rough indication of a grease's resistance to heat and a guide to manufacture. The difference between the highest temperature at which a grease can be used and the drop point varies very much between types. It is at its maximum with some soda greases and much smaller with multi-purpose lithium products and modern complex greases.

40.5 Additives

Much highly stressed modern machinery runs under conditions in which a straight mineral oil is not adequate.

Even the highest quality mineral oil can be unsatisfactory in response of its resistance to oxidation and its behaviour under pure boundary conditions, but it is possible to improve these characteristics by the addition of relatively small amounts of complex chemicals. This use of additives resembles in many ways the modification of the properties of steel by the addition of small amounts of other chemicals. It will be of value to have some knowledge of the effect of each type of additive.

40.5.1 Anti-oxidants

When mixed with oxygen, lubricating oil undergoes chemical degradation resulting in the formation of acidic products and sludge. This reaction, which is affected by temperature, the presence of catalysts such as copper and the composition of the oil, can be delayed by the inclusion of suitable additives.

Anti-oxidants are the most extensively used additives and will be found in oils and greases which are expected to operate for considerable periods or under conditions which would promote oxidation. Typical examples are crankcase oils and bearing greases.

40.5.2 Anti-foam

The entrainment of air in lubricating oil can be brought about by operating conditions (for example, churning) and by bad design such as a return pipe which is not submerged. The air bubbles naturally rise to the surface, and if they do not burst quickly, a blanket of foam will form on the oil surface. Further air escape in thus prevented and the oil becomes aerated. Oil in this condition can have an adverse affect on the system which, in extreme cases, could lead to an adverse affect on the system which, in extreme cases, could lead to machine failure. The function of an anti-foam additive is to assist in the burst of air bubbles when they reach the surface of the oil.

40.5.3 Anti-corrosion

The products of oil oxidation will attack metals, and this can be prevented by keeping the system free from pro-oxidative impurities and by the use of anti-oxidants. These additives will not, however, prevent rusting of ferrous surfaces when air and water are present in the mineral oil. The presence of absorbed air and moisture is inevitable in lubricating systems and therefore the oil must be inhibited against rusting. These additives, which are homogeneously mixed with the oil, have an affinity for metal, and a strongly absorbed oil film is formed on the metal surface which prevents the access of air and moisture.

40.5.4 Anti-wear

The increasing demands being made on equipment by the requirement for increased output from smaller units create problems of lubrication, even in systems where full-fluid film conditions generally exist. For instance, at start-up, after a period of rest, boundary lubrication conditions can exist and the mechanical wear that takes place could lead to equipment failure. Anti-wear additives, by their polar nature, help the oil to form a strongly absorbed layer on the metal surface which resists displacement under pressure, thereby reducing friction under boundary conditions.

40.5.5 Extreme pressure

Where high loading and severe sliding speeds exist between two metal surfaces, any oil film present is likely to be squeezed out. Under these conditions very high instantaneous pressures and temperatures are generated. Without the presence of extreme pressure additives the asperities would be welded together and then torn apart. Extreme pressure additives react at these high temperatures with the metal or another oil component to form compounds which are more easily deformed and sheared than the metal itself, and so prevent welding. Oils containing extreme pressure additives are generally used in heavily loaded gearboxes which may also be subjected to shock loading.

40.5.6 Detergent/dispersant

The products of combustion formed in internal combustion engines, combined with water and unburnt fuel, will form undesirable sludge which can be deposited in the engine and so reduce its operation life and efficiency. Detergent/dispersant additives prevent the agglomeration of these products and their deposition in oilways by keeping the finely divided particles in suspension in the oil. They are used in engine-lubricating oils where, when combined with anti-oxidants, they prevent piston-ring sticking. They are essential for high-speed diesels, and also desirable for petrol engines.

40.5.7 Viscosity index improvers

When mineral oils are used over an extended temperature range it is frequently found that the natural viscosity/temperature relationship results in excessive thinning out in the higher-temperature region if the desired fluidity is to be maintained at the lower region. The addition of certain polymers will, within limits, correct this situation. They are of particular value in the preparation of lubricating oils for systems sensitive to changes in viscosity such as hydraulic controls. They are also used in multigrade engine oils.

40.6 Lubricating-oil applications

There is a constant effort by both the supplier and consumer of lubricants to reduce the number of grades in use. The various lubricant requirements of plant not only limit the extent of this rationalization but also create the continuing need for a large number of grades with different characteristics.

It is not possible to make lubricants directly from crude oil that will meet all these demands. Instead, the refinery produces a few basic oils and these are then blended in varying proportions, together with additives when necessary, to produce an oil with the particular characteristics required. In some instances the continued increase in plant performance is creating demands on the lubricant which are at the limit of the inherent physical characteristics of mineral oil. Where the operational benefit justifies the cost, the use of synthetic base stocks is being developed.

Where these are considered for existing plant, seal and paint compatibility needs to be reviewed before such products are introduced. The problems which face the lubricant supplier can best be illustrated by looking at the requirements of certain important applications.

40.7 General machinery oils

These are lubricants for the bearings of most plant, where circulating systems are not involved. These are hand, ring, bottle or bath lubricated bearings of a very wide range of equipment; line shafting, electric motors, many gear sets and general oil-can duties. The viscosity of these oils will vary to suit the variations in speed, load and temperature.

While extreme or arduous usage conditions are not met within this category, the straight mineral oils which are prescribed must possess certain properties. The viscosity level should be chosen to provide an adequate lubricant film without undue fluid friction, though this may also be influenced by the method of application. For instance, a slightly higher viscosity might be advisable if intermittent hand oiling has to be relied upon. Although anti-oxidants are not generally required, such oils must have a reasonable degree of chemical stability (Figure 40.3).

40.8 Engine lubricants

The type of power or fuel supply available will influence the decision on prime mover to be used. This is often electric power, but many items of plant such as compressors, generators or works locomotives, will be powered by diesel engines, as will most of the heavy goods vehicles used in and outside the works.

The oils for these engines have several functions to perform while in use. They must provide a lubricant film between moving parts to reduce friction and wear, hold products of combustion in suspension, prevent the formation of sludges and assist in cooling the engine. Unless the lubricant chosen fulfils these conditions successfully, deposits and sludge will form with a consequent undesirable increase in wear rate and decrease in engine life.

40.8.1 Frictional wear

If the effects of friction are to be minimized, a lubricant film must be maintained continuously between the moving surfaces. Two types of motion are encountered in engines, rotary and linear. A full fluid-film between moving parts is the ideal form of lubrication, but in practice, even with rotary motion, this is not always achievable. At low engine speeds, for instance, bearing lubrication can be under boundary conditions.

The linear sliding motion between pistons, piston rings and cylinder walls creates lubrication problems which are some of the most difficult to overcome in an engine. The ring is exerting a force against the cylinder wall while at the same time the ring and piston are moving in the cylinder with a sliding action. Also, the direction of piston movement is reversed on each stroke. To maintain a full fluid oil film on the cylinder walls under these conditions is difficult and boundary lubrication can exist. Frictional wear will occur if a lubricant film is either absent or unable to withstand the pressures being exerted. The lubricant will then be contaminated with metal wear particles which will cause wear in other engine parts as they are carried round by the lubricant.

40.8.2 Chemical wear

Another major cause of wear is the chemical action associated with the inevitable acidic products of fuel combustion. This chemical wear of cylinder bores can be prevented by having an oil film which is strongly adherent to the metal surfaces involved, and which will rapidly heal when a tiny rupture occurs. This is achieved by the use of a chemical additive known as a corrosion inhibitor.

40.8.3 Products of combustion and fuel dilution

As it is not possible to maintain perfect combustion conditions at all times, contaminations of the oil by the products of combustion is inevitable. These contaminants can be either solid or liquid.

When an engine idles or runs with an over-rich mixture the combustion process is imperfect and soot will be formed. A quantity of this soot will pass harmlessly out

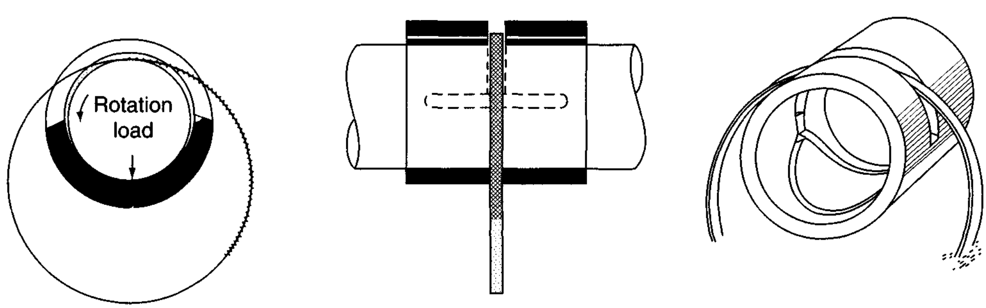

Figure 40.3 Ring oiled bearings

with the exhaust but some will contaminate the oil film on the pistons and cylinders and drain down into the crankcase. If there is any water present these solids will emulsify to form sludges which could then block the oilways. Filters are incorporated into the oil-circulation system to remove the solid contaminants together with any atmospheric dust which bypasses the air filters.

One of the liquid contaminants is water, the presence of which is brought about by the fact that when fuel is burnt it produces approximately its own weight in water. When the engine is warm this water is converted into steam, which passes harmlessly out of the exhaust. However, with cold running or start-up conditions this water is not converted and drains into the sump. Having dissolved some of the combustion gases, it will be acidic in nature and will form sludges.

Another liquid contaminant is unburnt fuel. A poor-quality fuel, for example, may contain high boiling point constituents which will not all burn off in the combustion process and will drain into the sump. The practice of adding kerosene to fuel to facilitate easy starting in very cold weather will eventually cause severe dilution of the lubricating oil. Excessive use of over-rich mixture in cold weather will mean that all the fuel is not burnt because of the lack of oxygen and again, some remains to drain into the sump.

Poor vaporization of the fuel will also produce oil dilution. Generally, this fuel will be driven off when the engine becomes warm and is running at optimum conditions. However, severe dilution of the oil by fuel could have serious results as the viscosity of the oil will be reduced to an unacceptable level.

40.8.4 Oxidation

The conditions of operation in an engine are conducive to oil oxidation, and this is another problem to be overcome by the lubricant. In the crankcase, the oil is sprayed from various components in the form of an oil mist which is in contact with a large quantity of air and at a fairly high temperature. Oxidation produces complex carbonaceous products and acidic material and these, combined with fuel contaminants, will form stable sludges. In the combustion chamber, where the temperatures are very much higher, the oil is scraped up the cylinder walls by the piston ascending at very high speeds and is again present in the form of an oil mist. A form of carbon deposit is produced by a combination of heat decomposition and oxidation. Some of this deposit will remain, but some will pass into the sump. The effect of oxidation adds to the problem of oil contamination by the products of combustion, resulting in the formation of a resin-like material on the pistons and hot metal parts known as 'laquer' and acidic material which will attack bearing metals such as copper-lead.

These problems of engine lubrication can be overcome by using a highly refined oil. The resistance to oxidation is further enhanced by the use of anti-oxidants. The addition of corrosion-inhibitors counters acidic materials produced by combustion at low engine temperatures.

Detergent–dispersant additives are incorporated so that the carbonaceous matter produced by imperfect combustion is retained in suspension in the oil, preventing it from being deposited on the engine surfaces. Such an oil is known as a fully detergent-type lubricant. All these additives are gradually consumed during operation and the rate of decline in their usefulness will determine the oil-change period. This rate is, in turn, influenced by the conditions of operation.

40.8.5 The SAE viscosity system

This classification was devised by the Society of Automotive Engineers (SAE) in America by dividing the viscosity span into four and giving each of the divisions a number – SAE 20, 30, 40 and 50. The thinnest (SAE 20), for example, covered the range 5.7–9.6 cSt specified at 210°F, which was considered to be a temperature typical of a hot engine. (The SAE originally specified temperatures in °F, because they was the convention. Today, temperatures are quoted in °C.)

Later, the SAE series was extended to include much thinner oils because of the growing demand for easier winter starting. The viscosities of the three new grades were specified at 0°F (typical of cold morning temperatures) and each was given the suffix W for Winter–SAE 5W, 10W and 20W. Later still, grades of 0W, 15W and 25W were added to satisfy the more precise requirements of modern engines (Table 40.3).

40.8.6 Multigrades

All oils become thinner when heated and thicker when cooled, but some are less sensitive than others to these viscosity/temperature effects. The degree of sensitivity is known as Viscosity Index (VI). An oil is said to have high VI if it displays a relatively small change of viscosity for a given change of temperature.

In the 1950s, development in additive technology led to the production of engine oils with unusually high VIs, known as multigrade oils. A multigrade oil's high resistance to temperature change is sufficient to give it the combined virtues of a thin grade at low (starting) temperatures and a thick one at running temperatures. An SAE 20W-40 multigrade, for example, is an thin at −20°C as a 20W oil, but as thick at 100°C as an SAE 40 oil. Thus the multigrade combines full lubrication protection at working temperatures with satisfactorily easy starting on frosty mornings. Figure 40.4 is a viscosity–temperature graph for six monograde oils and a 10W-40 multigrade, showing how the multigrade has the high-temperature properties of an SAE 40 oil and the low-temperature properties of an SAE 10W. Thus the multigrade is suitable for all-year-round use.

40.8.7 Performance ratings

The SAE numbering system refers purely to the viscosity of the oil, and is not intended to reflect lubricating performance (there is no such thing as an 'SAE quality' oil, for example). Engine oils are marketed in a range of performance levels, and need to be classified according to the severity of service conditions in which they are designed to operate. Accordingly, the American Petroleum Institute (API) has drawn up a coding system in which oils are subjected to a series of classifying bench-tests known as the 'Sequence' tests.

Table 40.3 Viscosity classification (engine oil viscosity classification–SAE J300 revised Dec. 1999)

SAE viscosity grade	*Low-temperature (°C) cranking viscosity (cP) max.*	*Low-temperature (°C) pumping viscosity (cP) max. with No yield stress*	*Low-shear-rate kinematic viscosity (cSt) at 100°C min.*	*Low-shear-rate kinematic viscosity (cSt) at 100°C max.*	*High-shear-rate viscosity (cP) at 150°C min.*
0W	6200 at −35	60 000 at −40	3.8	–	–
5W	6600 at −30	60 000 at −35	3.8	–	–
10W	7000 at −25	60 000 at −30	4.1	–	–
15W	7000 at −20	60 000 at −25	5.6	–	–
20W	9500 at −15	60 000 at −20	5.6	–	–
25W	13 000 at −10	60 000 at −15	9.3	–	–
20	–	–	5.6	<9.3	2.6
30	–	–	9.3	<12.5	2.9
40	–	–	12.5	<16.3	2.9[a]
40	–	–	12.5	<16.3	3.7[b]
50	–	–	16.3	<21.9	3.7
60	–	–	21.9	<26.1	3.7

[a](0W-40, 5W-40 and 10W-40).
[b](15W-40, 20W-40, 25W-40 and 40).

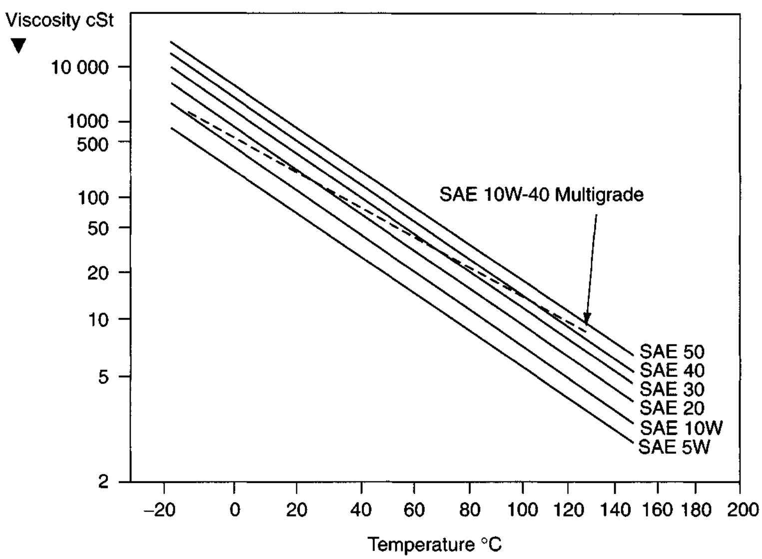

Figure 40.4 Multigrade chart

40.8.8 The API service classifications

In the API system the least demanding classification for a petrol engine was originally designated SA. The most demanding is, at present, SJ. (The S stands for Service Station.) Constant development of both engines and oils means that from time to time the highest ratings are superseded by even higher ratings. The API system also classifies diesel engine oils by their severity of service. Here the categories have the prefix C, which stands for Commercial.

40.8.8.1 Petrol engines

SA Service typical of engines operated under mild conditions. This classification has no performance requirements.

SB Service typical of engines operating in conditions such that only minimum protection of the type afforded by additives is desired. Oils designed for this service have been used since the 1930s; they provide only anti-scuff capability and resistance to oil oxidation and bearing corrosion.

SC Service typical of petrol engines in 1964–1967 cars and trucks. Oils designed for this service provide control of high- and low-temperature deposits, wear, rust and corrosion.

SD Service typical of 1967–1970 petrol engines in cars and some trucks; but it may apply to later models. Oils designed for this service provide more protection than SC against high- and low-temperature deposits, wear, rust and corrosion; and may be used where SC is recommended.

SE Service typical of petrol engines in cars and some trucks in 1972–1979. Oils designed for this service provide more protection against oxidation, high-temperature deposits, rust and corrosion than SD or SC, and may be used where those classifications are recommended.

SF Service typical of petrol engines in cars and some trucks from 1980. Oils developed for this service provide better oxidation stability and anti-wear performance than SE oils. They also provide protection against engine deposits, rust and corrosion. Oils meeting SF may be used wherever SE, SD or SC is recommended.

SG Service typical of petrol engines in cars, vans and light trucks during 1989 – 92. Oils developed for this service provide improved control of engine deposits, oil oxidation and engine wear relative to oils developed for previous categories. Oils meeting SG may be used wherever SF, SE, SF/CC or SE/CC are recommended.

SH Service typical of petrol engine warranty maintenance service in cars and vans during 1992 –1996. API SH oils cover the performance requirements of SG oils tested to the then latest CMA (Chemical Manufacturing Association-USA) protocol on engine testing, but define tighter manufacturing controls.

SJ Service typical of petrol engine warranty maintenance service for passenger cars and vans from 1996. API SJ oils cover the Engine test sequences as for SG, to the current CMA protocol, but with increased severity. SJ oils will provide better overall protection in terms of high and low temperature operation, lower volatility, improved foam control, fuel economy and catalyst compatibility.

40.8.8.2 Diesel engines

CA Service typical of diesel engines operated in mild to moderate duty with high-quality fuels. Occasionally this category has included petrol engines in mild service. Oils designed for this service were widely used in the late 1940s and 1950s; they provided protection from bearing corrosion and light-temperature deposits.

CB This category is basically the same as CA, but improved to cope with low-quality fuels. Oils designed for this service were introduced in 1949.

CC Service typical of lightly supercharged diesel engines operated in moderate to severe duty. Has included certain heavy-duty petrol engines. Oils designed for this service are used in many trucks and in industrial and construction equipment and farm tractors. These oils provide protection from high-temperature deposits in lightly supercharged diesels and also from rust, corrosion and low-temperature deposits in petrol engines.

CD Service typical of supercharged diesel engines in high-speed high-output duty requiring highly effective control of wear and deposits. Oils designed for this service provide protection from bearing corrosion and high-temperature deposits in supercharged diesel engines running on fuels of a wide quality range.

CDII Service typical of two-stroke cycle diesel engines requiring highly effective control over wear and deposits. Oils designed for this service also meet all the requirements of CD.

CE Service typical of certain turbocharged or supercharged heavy-duty diesel engines operating under both low speed-high load and high speed-low load conditions. Oils designed for this service must also meet the requirements specified for CC and CD classifications.

CF-4 Introduced 1990 for high speed, four stroke diesel engines. CF-4 specification provided improved oil control consumption and piston deposits over CE category.

CF Introduced in 1994 for service typical of indirect injected diesel engines which can be naturally aspirated, super or turbo-charged.

CF-2 Introduced 1994 for service typical of two-stroke diesel engines requiring highly effective control of wear and deposits. Essentially API CF plus Detroit Diesel 6V-92TA test. CF-2 is a direct replacement of CDII.

CG-4 Introduced 1995 for use in high speed four stroke diesel engines used in commercial vehicles with fuel sulphur content less than 0.05% wt and off-highway engines using fuel with sulphur content less than 0.5% wt. CG-4 specification oils, formulated for engines meeting the 1994 exhaust emission standards, could be used in engines requiring API CD, CE and CF-4 oils. CG-4 oils provided control over high temperature deposits, wear, corrosion, foam, oxidation stability and soot concentration.

CH-4 Introduced in 1998 for use in high speed, four stroke diesel engines designed to meet the 1998 exhaust emissions standards. Oils to this performance level are formulated for use with diesel fuels containing up to 0.5% sulphur by weight. CH-4 oils can be used in engines where CF-4 or CG-4 are quoted.

Before an oil can be allocated any given API performance level it must satisfy requirements laid down for various engine tests. In the SJ category, for example, the engine tests include the following:

Service IID measures the tendency of the oil to rust or corrode the valve train and to influence the value lifter operation.
Sequence IIIE measures high-temperature oil oxidation, sludge and varnish deposits, cam-and-tappet wear, cam and lifter scuffing and valve lifter sticking.
Sequence VE evaluates sludge deposits, varnish deposits, oil-ring clogging and sticking, oil-screen plugging and cam wear.
CRC L-38: the characteristics assessed are resistance to oxidation, bearing corrosion, tendency to formation of sludge and varnish, and change of viscosity.

In the CH-4 category the tests are:

Caterpillar 1K: the lubricant characteristics determined are ring sticking, ring and cylinder wear, and accumulation deposits under more severe test conditions than those for Caterpillar IH2.

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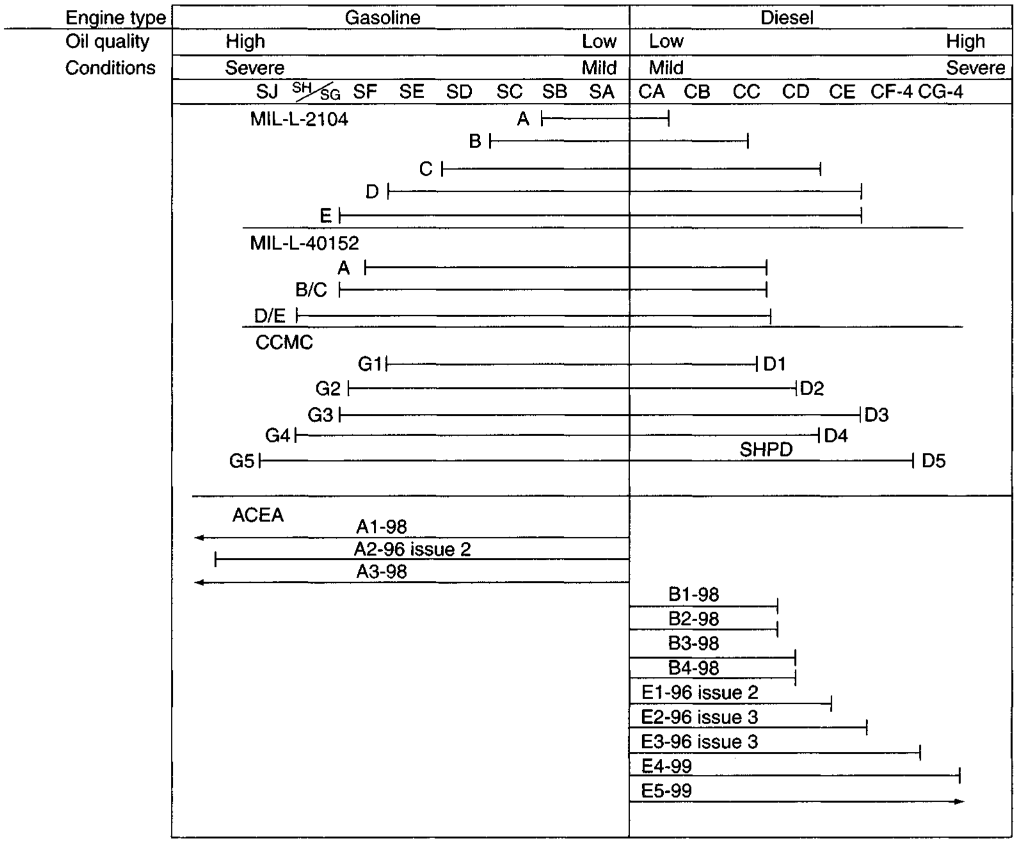

Figure 40.5 Approximate relationship between classifications and test procedures

Cummins M11 evaluates engine sludge crosshead wear and filter pressure.
Mack T8-E, evaluates oil thickening.
Mack T9 evaluates liner & piston ring wear

40.8.8.3 Other specifications

Various authorities and military bodies issue specifications relating to the service performance of engine oils. In some instances the ratings are almost identical with those of the API, but most of them are not precisely parallel because they cover performance factors encountered in particular engines and particular categories of service.

The most common of the other specifications are those with the prefix MIL, issued by the US military authorities. MIL-L-2104F approximates to the API CE rating for diesel lubricants, although it also relates to petrol engines that require API SE performance. MIL-L-46152D covers oils for both diesel and petrol engines, and approximates to API SG/CC (Figure 40.5).

40.9 Gear lubricants

There are few engineering applications in which gears do not play an essential part. They can be used to reduce or increase speed, transmit power and change the direction or position of a rotating axis. There are several types of gears to suit these varying operational conditions, such as spur, helical, plain and spiral bevels, hypoid, worm and wheel (Figure 40.6).

Extremely high pressures are developed between meshing teeth as, in theory, they only have point or line contact. Together with the sliding between mating surfaces which is always present it is clear that, if there is metal-to-metal contact, rapid wear will occur. The function of the lubricant is to provide and maintain a separating film under all the variations in speed, load and temperature. It must also act as a coolant and protect the gears against corrosion.

The lubrication of gears is not a simple matter, because of their shape and variability of motion. Fundamental factors which affect their lubrication are gear characteristics, materials, temperature, speed, loading, method of applying the lubricant and environment.

40.9.1 Gear characteristics

40.9.1.2 Spur, bevel, helical and spiral bevel gears

Providing the speed is sufficient and the load does not squeeze out the lubricant, the effect of rotating these gears is to produce a hydrodynamic wedge of a relatively