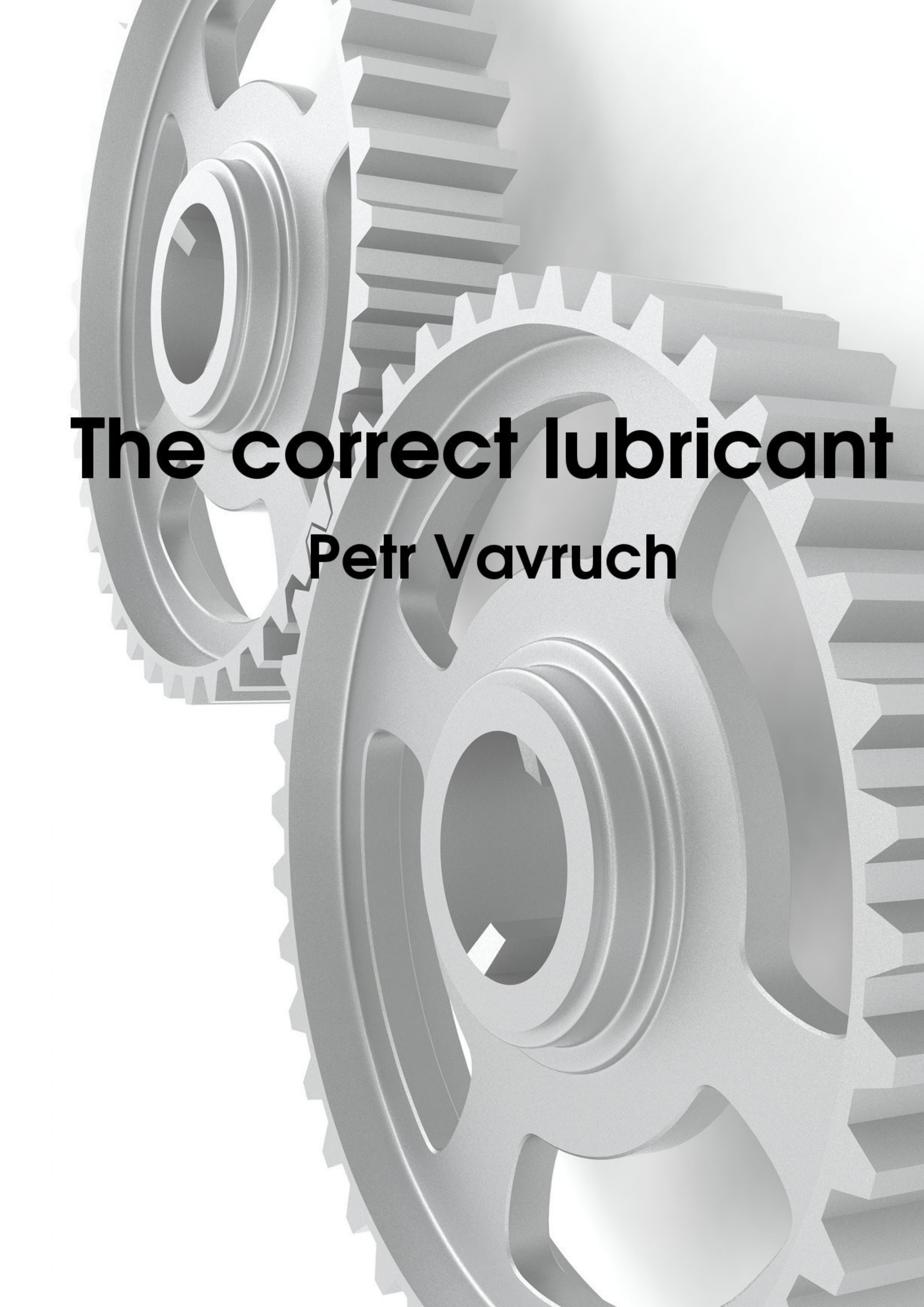


The correct lubricant

Petr Vavruch

DISCLAIMER

This book was first developed for a two-day workshop that was successfully run many times. In this text, it has been adapted for individual study and as a ready reference book with practical answers about a variety of lubricants.

Lubricants cannot be learnt in two days or by reading one book. When solving lubrication problems, there are always many aspects and we cannot consider all of them in one book. Also, a lot of practical experience is needed. Thus you cannot rely on this book to give you all the ammunition you need to solve lubrication problems.

The author will not be held liable or responsible for any loss, damage or any other occurrence whatsoever resulting from the use of this book.

Always consult your lubricant supplier!

What can be achieved is basic understanding of lubricants. The book will allow plant and fleet personnel to better understand the oil supplier's representatives, both salesmen and field engineers – some of whom have been trained to talk about 'benefits' and 'features' and lose sight of what is essential (this book could help them, too). After studying this book, you should know what is essential. So you will be able to ask the right questions and get meaningful answers. But you will not become an expert – not yet.

This is a practical manual with very little chemistry and lubrication theory – only as much as is necessary to understand the subject.

There is a website that works with this book to aid deeper study. To access the links while reading the book on-line, click on 'Web' on almost every page. If you cannot do it while reading the book, you can later access just one address

http://correctlubricant.co.za/web_book.php

which will allow you to open all the links. The list incudes additional sections that are not covered in this book.

You can also communicate with the author by using the above Internet address. Two-day workshops can be arranged on 'all-expanses-plus-moderate-fee' basis as the author likes to present his workshop. The workshop presentation is fully illustrated.

Due to its practical nature, there are some branded products and links to company literature mentioned in the book. They are just examples and it does not mean that the author endorses, recommends or prefers those products. As the product lines change all the time, the mentioned product might not be available in your country when you are reading this. But the main reason for including company literature is that it often includes useful technical information of general nature.

It is impossible to acknowledge all the sources for this book. The information originates from various courses, conferences, discussions, publications, web pages, problems, mishaps and troubleshooting during the author's working life and beyond. All of it is common knowledge among lubrication professionals. We, of course, never stop learning.

There are new developments all the time: oil-miscible synthetic PAG, nano-technology, lubrication of electric cars, etc. As this is a practical book, most of these developments that are not yet widely commercialized are not included.

OVERVIEW

This book covers basic practical information about lubrication and lubricants. It starts with the idea of always considering three main aspects first. They are:

(1) base oil quality which often makes all the difference,
(2) specific performance for each application, e.g. the level of protection against wear,
(3) viscosity (how easily the oil flows).

For greases, there are two additional aspects:

(4) the nature of the thickener which often makes all the difference,
(5) consistency (how hard or soft the grease is).

Viscosity, the most important lubricant characteristic in both oils and greases, is covered first, together with viscosity index. Then some other important characteristics, followed by base oils including some synthetics, and finally the critical performance requirements for various applications.

The second part of the workshop deals with applications, starting with engine oils, then automotive gear and transmission oils, greases, industrial gear oils, circulating oils, compressor oils, hydraulic fluids, fire-resistant fluids, machine tool oils, oil cleanliness, storage and storage stability, finally briefly rust preventives and cutting fluids.

In addition to the essential requirements in each application, this part focuses on the difficult question: When is it advisable, or even necessary, to use synthetic lubricants?

The last part is included for people who use the book as a textbook. They will be challenged to find the correct lubricants to solve various practical problems. If the learners manage to complete this task, they will show that they have learned a great deal about lubricants.

To help the learners remember important aspects of each chapter, there are many questions and also three revisions in the text. The answers are at the end of the book and on a web page. It is recommended that learners check the answers even when they believe that they know them.

In this book, we had to exclude automotive specialities (except brake fluid – briefly), degreasing fluids, chain saw oils, air tool lubricants and rock drill oils, heat transfer oils and quenching oils, wire rope lubricants, chain lubricants (hot and cold), rolling oils, mould release oils, marine specialities and aviation products (except one oil and one grease), among lubricant types silicones and various ethers, among additives graphene. All that is too specialized.

Revision 28 September 2023
https://correctlubricant.co.za/Correct_lubricant.pdf

CONTENTS

ABOUT THE AUTHOR

Petr Vavruch, Pr Eng, Ing. (Prague), spent most of his working life with Mobil Oil and its successor from 1989 (due to sanctions against apartheid South Africa) Engen.

He is a senior member of engineering societies in South Africa and, during his career at Engen, was also a member of STLE where he presented two papers at annual meetings.

After graduating from the Czech Technical University in Prague, he helped to design original automatic transmissions for road vehicles. In South Africa, he worked in the Chrysler car factory, designed instruments at the CSIR, and worked in the Mechanical Research Department of Eskom.

At Mobil, Petr was a Field Engineer (Fuels & lubricants), Administrative Manager of Mobil Diesel Club and a Planning Engineer for automotive engine oils and other lubricants.

During the last 10 years at Engen, Petr was in charge of specifications and formulations of industrial and marine lubricating oils and specifications of base oils – also helping to solve production and field problems with these products.

Petr participated in or was in charge of a number of projects, e.g. new air compressor oils, synthetic lubricants, the universal diesel engine oil, a new range of engine oils, metalworking fluids, hydraulic fluids, industrial gear oils, open gear oils, turbine oils, marine engine oils and refrigeration oils.

He is now retired, has written a textbook for technical colleges and edited a number of 'Technology' textbooks for high schools. He lectures for The South African Institute of Tribology and The South African Institution of Mechanical Engineering.

He also worked several years part-time at the University of Cape Town helping 2nd and 3rd year students with mechanical design. Once a year, he is an external examiner at the Department of Mechanical and Mechatronic Engineering of the University of Stellenbosch.

Petr Vavruch retired at the age of 81 in November 2023.

1. THREE BASIC ASPECTS OF LUBRICATING OILS

It is always a good idea to consider three basic aspects of every lubricating oil first:

1. Base oil. Base oil (or 'base stock') brings the essential quality to the lubricant. If the quality of the base oil is not good enough, the performance of the finished lubricant might not meet requirements.

There are many types of base oils and we can group them as (a) paraffinic, (b) naphthenic and (c) synthetic. There are about 25 types of synthetic lubricants, of which we will cover just a few: PAO, PAG and some esters. Paraffinic and naphthenic types are 'mineral' base oils because they are extracted from crude oils. They are mixtures of all shapes of hydrocarbon molecules, plus some impurities. Some of the mineral base oils are much better refined and their molecules have been re-shaped (section 1.9).

2. Performance (Additives). In some applications, the quality of the base oil ensures the right performance – for example in lubricants for refrigeration compressors. In most cases however the performance comes from the right 'performance additives'. Additives are chemicals that must be added to suitable base stocks and typical lubricating oils are mixtures of base stocks and additives. There are many additives, but some are performance additives that are crucial in specific applications, they ensure the required performance (section 1.10).

Because mineral base oils react with oxygen ('oxidise'), most mineral based lubricating oils contain oxidation inhibitors ('anti-oxidants'). Because base oils do not provide sufficient protection against rust in the presence of moisture, most lubricating oils contain rust inhibitors. Lubricating oils with only rust and oxidation inhibitors are called R&O oils. Turbine oils are very high quality R&O oils, the quality comes from the correct base oils. There is no need for performance additives in turbine oils but other additives are present, e.g. demulsifier (1.11).

3. Viscosity (and viscosity index – VI). Viscosity is the most important characteristic of a lubricating oil. The right viscosity is achieved by mixing suitable base stocks – unless a base stock of exactly the right viscosity is available. Viscosity can also be modified by some additives. Because of its importance, we will discuss viscosity first.

Correct viscosity means that the oil has the ability to lubricate.

The viscosity of a lubricating oil changes with temperature. With increased temperature, it drops. The viscosity index (VI) tells us how much the viscosity changes with temperature. A high VI means that the viscosity changes less when the temperature changes – more in 1.4.

Web

Questions 1.0 (the answers are at the end of the book and are also available online):

1. What are the three groups of base oils? ....
2. Which two groups of base oils are called mineral and why? ....
3. What are R&O oils? ....
4. What do you achieve by having the right viscosity? ....
5. How does viscosity change with temperature? ....

1.1 Viscosity

Viscosity is the most important characteristic of lubricating oils and, what is often forgotten, it is also important in greases. Viscosity is the resistance to movement. Water flows fast so it has low viscosity. Honey has a high viscosity. We call an oil that has a low viscosity 'light' or 'thin'. High viscosity lubricants are 'heavy' or 'thick'. That is jargon.

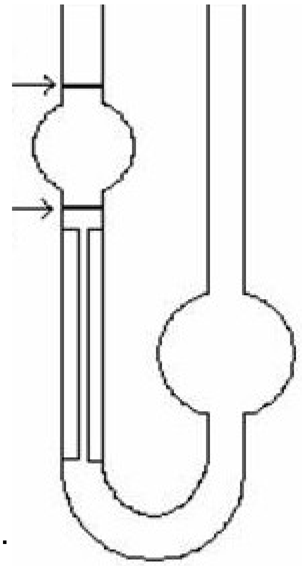
If we measure the viscosity by watching how fast the liquid flows, we measure 'kinematic viscosity'. In this case gravity is involved and the oil's density plays a role. In the picture, oil is in the top left bulb and flows into the bigger lower right hand side bulb. We measure the time it takes for the oil to drop from the top mark (top arrow) to the lower one.

If we measure the viscosity by the fluid's resistance when we stir it, we measure 'dynamic viscosity' (sometimes called 'absolute') and gravity and density play no part in it. (Some authors are using the term 'absolute' incorrectly.)

Kinematic viscosity (KV) is correctly reported in mm^2/s. However, we often use the old name for mm^2/s: centistoke (cSt). The dynamic viscosity unit is mPa.s (or centipoise, cP).

Dynamic viscosity (mPa.s) = Kinematic viscosity (mm^2/s) x Density (kg/litre)

(Not much difference between them because the density of most oils is around 0.85; water's density is 1.0)



As viscosity changes with temperature, it must always be reported at a specific temperature. For industrial lubricants, the standard reporting temperature is 40 °C, while for automotive, it is 100 °C. Some typical examples of kinematic viscosities, all at 40 °C:

High velocity spindle oils: 22 mm^2/s or much less
Automatic transmission fluids: 40 mm^2/s or less
Hydraulic fluids, turbine oils, screw compressor oils: 32 to 68 mm^2/s
Machine tool oils: 68 or 220 mm^2/s
Automotive engine oils used to take SAE 30 (see the next page): 100 mm^2/s
Air compressor cylinder lubricants: 100 or 150 mm^2/s
Industrial gear oils: 150-460 mm^2/s, typically 220 or 320 mm^2/s
Open gear lubricants: 1500 mm^2/s or much more

Viscosity of industrial oils are usually given as ISO Viscosity Grades (ISO VG).
(ISO: International Organization for Standardization, an independent, non-governmental organization)

The common ISO VG are **10, 15, 22, 32, 46, 68, 100, 150, 220, 320, 460, 680, 1000**.

ISO VG 100 means that the oil's viscosity at 40 °C is 100 mm^2/s ± 10%, that is between 90 mm^2/s and 110 mm^2/s. This works for most ISO viscosity grades, thus
ISO VG 150 oils have a viscosity of 150 mm^2/s ± 10%, that is between 135 and 165 mm^2/s.

There are gaps, e.g. an oil with a viscosity of 120 mm^2/s at 40 °C cannot be described using ISO VG, and would not normally be used as an industrial lubricant. Look again at the above examples to see how they comply with the ISO VG system.

The big word for viscosity considerations is 'rheological'. By definition, rheology is the science dealing with the flow and deformation of matter.

Web

Questions 1.1:

1. What is a 'heavy' oil? ....
2. In measuring what viscosity is gravity involved? …...
3. At what temperature do we measure the viscosity of industrial lubricating oils? ....
4. At what temperature do we measure the viscosity of automotive oils? …............................
5. Is ISO VG 68 a typical viscosity for industrial gear oils? …...
6. What are the viscosity limits of an ISO VG 220 oil? ....

1.2 Viscosity of engine oils (SAE – Society of Automotive Engineers, USA)

The viscosities of automotive and marine lubricants are classified using SAE viscosity grades (SAE J300), commonly called 'SAE numbers'. The grades with 'W' originally meant 'winter'. 'W' never meant 'weight' – that is ugly, only in the USA, slang.

Engine oil viscosity grades are **0W, 5W, 10W, 15W, 20W, 25W, 8, 12, 16, 20, 30, 40, 50, 60**.

Kinematic viscosity (KV) limits for SAE viscosity grades are given at 100 °C. To satisfy SAE numbers without the letter W, minimum and maximum is given – see the table below. However, for grades with W (shown in the web links) only minimum viscosities at 100 °C are specified but further limits are in tests at very low temperatures (see the example below the table).

SAE viscosity grade	**Viscosity, mm^2/s at 100 °C**		**High-temperature high-shear viscosity minimum at 150 °C, mPa.s**	**Comment**
	Minimum	**Maximum**		
8	4.0	<6.1	1.7	8, 12 and 16 are new
12	5.0	<7.1	2.0	KV overlap
16	6.1	<8.2	2.3	KV overlap
20	6.9*	<9.3	2.6	*was 5,6
30	9.3	<12.5	2.9	
40	12.5	<16.3	3.7*	*2.9 in 0W-, 5W-, 10W-
50	16.3	<21.9	3.7	
60	21.9	26.1	3.7	

High-temperature high-shear, HTHS, (also called 'high-shear-rate dynamic viscosity') is an indicator of an engine oil's resistance to flow in the narrow confines between fast moving parts in fully warmed up engines.

An oil that complies with two SAE viscosity grades (one with W and one without W) (e.g. 80W-90; 15W-40; 20W-50) may be called a 'multi-grade'. For example, SAE 15W-40 means that the oil is a multi-grade and satisfies both SAE 15W and SAE 40 specifications as follows:

1) Kinematic viscosity at 100 °C**:** 12.5 to less than 16.3 mm^2/s (15W minimum is 5.6 mm^2/s)
2) Cold cranking viscosity (CCS) at -20 °C: maximum 7000 mPa.s (SAE 15W)
3) Low temperature pumping viscosity (MRV) at -25 °C: maximum 60000 mPa.s (SAE 15W)
4) High-temperature high-shear test at 150 °C: minimum 3.7 mPa.s

Cold cranking simulator (CCS) simulates the condition in crankshaft bearings during cold start up. Cold pumpability measures viscosity of an oil that needs to be pumped through the engine after a cold start. Dynamic viscosity is used because kinematic viscosity cannot be measured at low temperatures – when the oil does not readily flow.

MRV is Mini-Rotary Viscometer: a rotating cylinder (a disk for light liquids) is submerged in the tested oil and the viscosity is determined by the power needed to turn the cylinder.

Web

Questions 1.2:

1. How many engine oil SAE viscosity grades are there? …...
2. Are there maximum kinematic viscosity limits for SAE grades with W? …..........................
3. Which SAE grades are recently introduced? …..
4. What is a multi-grade oil? …...
5. Could we have an SAE 30-40 multi-grade? ….. Why? …..
6. Is CCS relevant to SAE 40? …..

1.3 Viscosity of automotive gear oils

SAE J306 Standard		Original		From February 2019	
SAE Viscosity Grade	**Maximum temperature for viscosity of 150 000, mPa.s (°C)**	**Viscosity @ 100 °C (mm^2/s) minimum**	**Viscosity @ 100 °C (mm^2/s) maximum**	**Viscosity @ 100 °C (mm^2/s) minimum**	**Viscosity @ 100 °C (mm^2/s) maximum**
70W	-55	4.1	-	3.8	-
75W	-40	4.1	-	3.8	-
80W	-26	7.0	-	8.5	-
85W	-12	11.0		11.0	-
65	-	-	-	3.8	<5.0
70	-	-	-	5.0	<6.5
75	-	-	-	6.5	<8.5
80	-	7.0	<11.0	8.5	<11.0
85	-	11.0	<13.5	11.0	<13.5
90	-	13.5	<24.0	13.5	<18.5
110	-	-	-	18.5	<24.0
140	-	24.0	<41.0	24.0	<32.5
190	-	-	-	32.5	<41.0
250	-	41.0	-	41.0	-

Grades SAE 110 and SAE 190 introduced in 2006 are, with a few exceptions, ignored.

Gear oils do not have the 'high-temperature high-shear' requirement but they have a shear stability test that simply specifies that the kinematic viscosity of the oil must not drop below its minimum limit. For grades with W, only minimum viscosities at 100 °C are specified but further limits are there for a test at very low temperatures (see the table).

Questions 1.3:

1. How many automotive gear oil SAE viscosity grades are there? ....
2. Are there gaps or overlaps in KV limits in SAE 80 through 250? …......................................
3. The test not shown in the above table is …..
4. Which grades are tested for temperature at which the oil is 150000 mPa.s? ....
5. What are the SAE viscosity grades without W of both engine and gear oils having viscosities at 100 °C: (a) 15 mm^2/s .... (b) 25 mm^2/s? ....

1.4 Viscosity index

The viscosity index (VI) is an arbitrary figure designed to indicate a lubricant's viscosity changes with temperature. It has no physical meaning, so there is no unit of measurement (like mm^2/s for viscosity), it is just a number. It can be estimated using nomograms or found in reference books or calculated using calculators on the Internet.

Low VI means a large change in viscosity with changes in temperature. In other words, the oil becomes extremely thin at high temperatures and extremely thick at low temperatures. Conversely, a high VI means less change in viscosity over a wide temperature range. However, the viscosity of all oils changes quite a lot with changing temperatures.

To get a high VI, we use base oils with a high VI, e.g. synthetics, or we can use additives – viscosity modifiers (VM), previously called viscosity index improvers (VII). Or both methods. Typical VI for various lubricants are:

Paraffinic Group I	around 100	Multi-grade oils	135-200
PAO	135-160 or more	Esters	140-190
Vegetable oils	195-210	PAG	200-220

Web

1.5 Pour point

Oils can become quite thick at low temperatures. In fact, at certain temperatures, they stop flowing altogether. The pour point of an oil is the lowest temperature at which it shows signs of moving under prescribed conditions. At this low temperature, the oil is no longer pumpable.

When we compare similar oils, heavier oils have higher (worse) pour points and light oils have lower pour points as we can see in the following table:

Oil type	**ISO VG 68**	**ISO VG 150**	**ISO VG 320**
R&O circulating oils	-12 °C	-9 °C	-6 °C
Industrial gear oils	-24 °C	-21 °C	-18 °C

Both R&O circulating oils and industrial gear oils in our example contain the same base oil mixtures in the same viscosity grade, e.g. VG 68. The difference is that R&O circulating oils do not contain a special additive called pour point depressant and industrial gear oils contain a lot (section 6.). Thus the R&O figures show the pour points of the base oil blends.

Pour point is a problem of paraffinic base oils because they contain, among all other shapes, too much of long straight paraffinic molecules that are by their nature waxes. Waxes are solid even at relatively high temperatures. Naphthenic and synthetic base stocks have much lower pour points. More about base oils later.

You might have noticed that pour points are traditionally reported in multiples of 3:
-6, -9, -12, -15, -18, -21 °C etc. This is due to the original laboratory test method used.

Web

Questions 1.5:

1. What is the name of the additive used to improve pour points? ....
2. Do synthetic and naphthenic base oils have good (low) pour points? ....

1.6 Flash point and Noack volatility

The flash point is the oil temperature at which so much oil vapour is generated that it can be, for a fraction of a second, ignited when exposed to an open flame – it flashes. There are two test methods giving different results but, generally, flash points of lubricating oils are between 170 and 260 °C. Volatility cannot be fixed with additives, it depends on the base oil. Thus it is one of the important tests in base oil production.

If you heat the oil further and there is enough vapour so it does not just flash but the burning continues, at the oil temperature about 30 °C higher than the flash point, it is called fire point. It is wrongly assumed that the flash and fire points have a direct bearing on fire hazard. During a fire, the oil is heated far beyond the fire point so a higher fire point does not make much difference.

In the Noack test, the mass of oil that boils off in 1 hour at 250 °C is measured. The result is important in engine oils because modern engine oil specifications include the maximum allowed limit, usually 15%, driven environmentally: vapour emissions and fuel economy.

High Noack could mean more oil vapour in the environment, higher oil consumption as well as higher fuel consumption due to the thickening of the remaining oil in the engine when the light fractions have evaporated. The thicker oil spoils fuel economy.

API CI-4 PLUS diesel engine oil category (section 3.2) and ACEA (section 3.6) require a lower Noack: 13% maximum (ACEA C4 even 11% maximum).

Web

1.7 EXERCISE

On the next page, there is a viscosity-temperature chart. Print it if you can, use a pencil and a ruler and draw the viscosities of all the lubricants listed in the following table. Steps: 1) Mark the value of the viscosity at 40 °C, e.g. 230 centistokes, above '40' in the chart and the value of the viscosity at 100 °C, e.g. 27.6 cSt, above '100'. 2) Connect both points with a straight line.

The line is straight because the viscosity scale is designed to make it straight - look how strange the scale is: 2 to 10 cSt takes more than a third of the chart, more than from 100 to 4000 cSt.

Step 3) Extend the straight lines to the left to the edge of the chart (above '0'). Identify the lines by lubricant names or just write the relevant values of VI on top of the lines. It is highly recommended that you do all these steps by hand – you will understand it much better.

But if you cannot draw the lines, then Ctrl-Click here or go to CHARTS in the book. Study the slopes of the lines with different VI: e.g. the slopes of SAE 30 and ISO VG 32 are the same because their VI is the same, and the line marked '65' is much steeper than the line '214'.

Lubricant	**Kinematic viscosity (KV), mm^2/s**		**VI**	**KV**	
	at 40 °C	**at 100 °C**		**at 0 °C**	**at 70 °C**
Synthetic gear oil	230	27.6	155		
SAE 20W-50 engine oil *	135	17.2	139		
Synthetic engine oil	125	22.9	214		
SAE 30 engine oil	100	11.4	102		
Refrigeration compressor oil	55	6.5	65		
Hydraulic oil ISO VG 32	30	5.2	102		

* Note the viscosity at 40 °C of SAE 20W-50 engine oil, it will be of interest later

To appreciate how thick lubricants can become at low temperatures, read the viscosities at 0 °C (above '0') of all oils in the chart and write them into the above table in the column 'at 0 °C'. Read the viscosities at 70 °C of all oils and also write them into the above table (see web or 1.7 in ANSWERS).

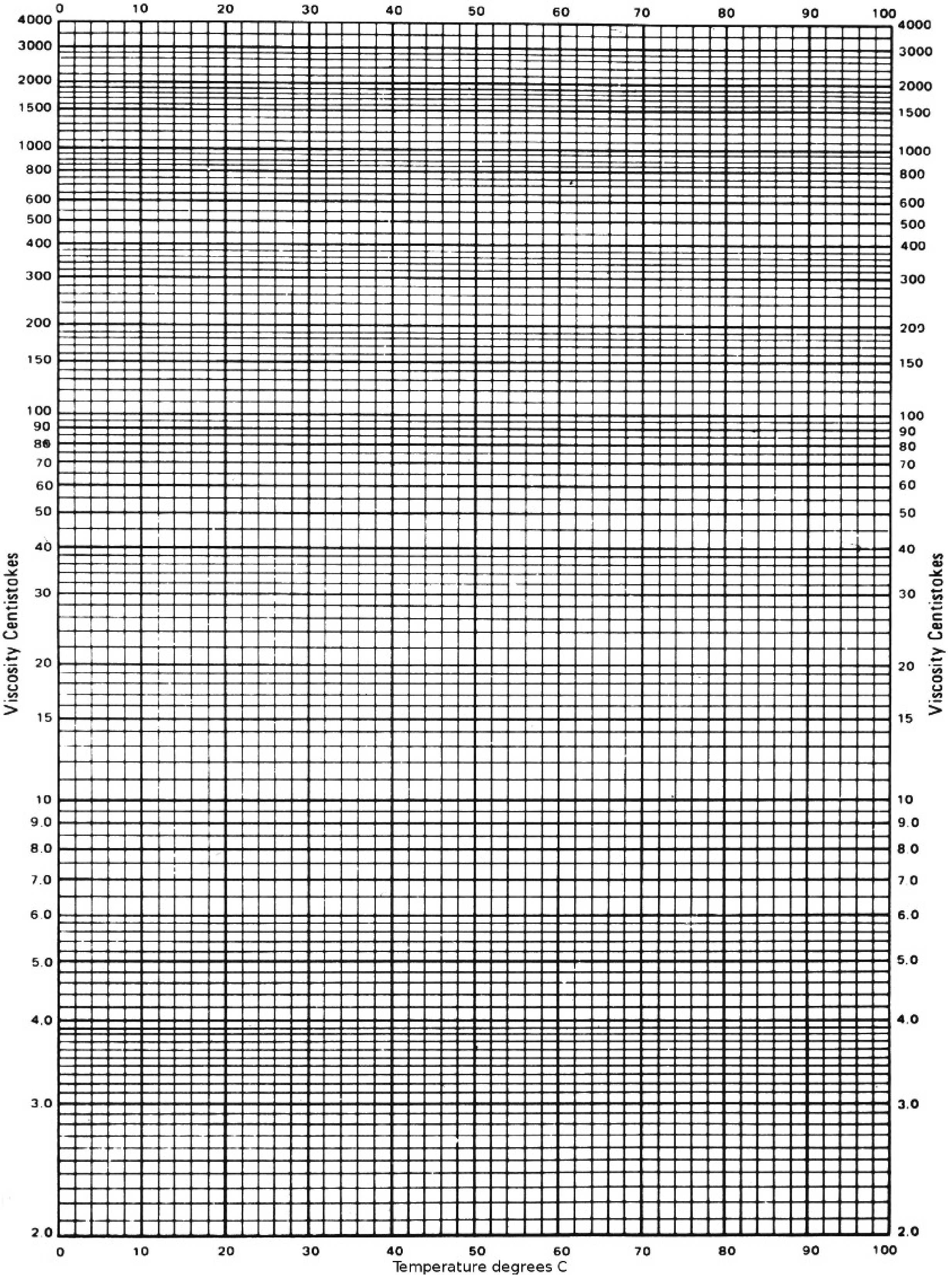
Questions 1.7:

1. What does a low viscosity index mean? ....
2. Does a low viscosity index oil have a steep or not so steep line in the chart? …..................
3. What is the unit of measurement of VI? ....
4. You have added values at 70 °C in the above table. Are the values at 70 °C averages of the values at 40 °C and 100 °C (that means exactly in the middle between the values at 40 °C and 100 °C)? …........ Why? ....

Web

The chart on the next page is a simplified one, made to be dual purpose (see Web or CHARTS page 68). The viscosity scale (the scale modification is called log-log) is correct for the purpose but intervals for temperature (horizontal intervals) are equal (from 0 to 10 is the same interval as from 90 to 100). That is not strictly correct. Compare this chart with the chart on page 52. There, the intervals for temperature are slightly diminishing from left to right.

If you can, use this opportunity to draw additional lines in the chart on page 52 for future use. You have lines there for ISO VG from 22 to 100. Add lines for ISO VG 150, 220, 320 and 460. Steps: 1) Mark the points above 40 °C at viscosities of 150, 220, 320 and 460 mm^2/s. 2) Draw lines parallel to the line '100' through those four points. If you cannot print and draw, see Web or the last page in this book.



Viscosity-temperature chart (simplified – dual purpose)

Web

1.8 **Foam, entrained air and air release**

All liquids foam when they are agitated, for example, the water in our picture. In lube oils, foam is a collection of closely packed air bubbles surrounded by thin films; it floats on the surface of the oil. It is cosmetic, leave it alone! It must be treated if it spills over the sides of the tank onto the floor creating both a safety hazard and waste, or if it is sucked into the circulation causing the foam to be circulated instead of oil – only then you might have to add a defoamant.

The laboratory test method for foam is simple but the test results look complicated:

Foam tendency 260/70/250:
Air was blown through a column of oil that was kept at 24 °C (75 F) for 5 minutes – forming foam on the top of the column. In our example, the foam reached the 260 millilitre mark. This first figure is called Sequence I.

Another sample of the same oil was heated to 93.5 °C (200 F) and again air was blown through the oil – the foam reached 70 ml. This is called Sequence II.

After the oil cooled down to 24 °C, air was blown–the foam reached 250 ml – Sequence III.

Foam stability 30/0/20:
After each of the above Sequences, air blowing was stopped for 10 minutes and the foam level was recorded. In our example, the foam dropped to the 30 ml mark after Sequence I, to 0 ml (no foam left) after Sequence II, and to 20 ml after Sequence III.

Foam 50/0:
This is another way of reporting. Foam tendency in Sequence I was 50 ml and foam stability in Sequence I was 0 ml (no foam left). Sequences II and III were not done.

The three sequences differ only in oil temperature. Hydraulic fluid specifications often include only foam stability limits.

Air is not only found as bubbles on the surface of oils. In fact, air is dissolved in oils – causing no problem unless it suddenly comes out in the oil (is no longer dissolved) when the pressure drops in pump suction or at orifices – forming bubbles in the oil. Bubbles in oil are called **entrained air**. The speed by which these bubbles come to the surface is called air release. Air release can be spoilt (!) but not improved by additives. Defoamants spoil the air release!

The ability of a hydraulic, turbine or other circulating oil to separate entrained air is a key performance characteristic in applications where agitation causes a dispersion of air bubbles in the oil. To determine air release properties, the sample is heated to 50 °C and air is blown into it. After the air flow has been stopped, the time required for the air still entrained in the oil to come down to 0.2% of the oil's volume is the air release result. It is quite a tricky laboratory test to perform. A typical result in ISO VG 46 hydraulic oil is 7 minutes, the maximum limit is 10 minutes. Turbine oils also need good air release.

Web

Questions 1.8:
1. When should you start worrying about foam on the top of the oil surface? …......................…
2. What are defoamants and what could they spoil? …...
3. What is a good air release result for ISO VG 46 hydraulic oil? …..
4. Two oils (a) and (b) have been tested. Which foam results are **better** and why?

(a) Foam 180/10; (b) Foam tendency 190/0/120, foam stability 20/0/0.

1.9 Base stocks

More than 20 years ago, the American Petroleum Institute (API) divided paraffinic base oils into three categories; Group I represented conventionally refined mineral base stocks while modern paraffinic base stocks, that are severely hydro-treated, are in Groups II and III:

API Base Stock Categories (API Publication 1509 of 1993)				
Group	**Sulphur, % mass**		**Saturates, % mass**	**VI**
I	>0.03	and/or	<90	80-119
II	≤0.03	and	≥90	80-119
III	≤0.03	and	≥90	≥120
IV	All polyalphaolefins (PAO)			
V	All other: other synthetics, e.g. PAG, vegetable and naphthenic oils			

'Saturates' means molecules with single bonds such as paraffinic and naphthenic hydrocarbons – as against, for example, aromatic hydrocarbons that are not saturated as they always have double bonds. Double bonds can break in reaction with other atoms – e.g. with oxygen causing oxidation (it's a bit more complicated: it takes a few steps to oxidise hydrocarbons).

Group II and III base oils are different from Group I base oils because they contain significantly lower levels of impurities, e.g. sulphur and aromatic hydrocarbons – see the table – but also less polar compounds and nitrogen. Molecules that are 'polar' have ends ('heads') that are more reactive than the other ends (also more reactive than molecules that do not have heads, e.g. hydrocarbons). The heads can react with other molecules or attach themselves to metals or additives etc.

Group II and III base oils are so pure that they are almost colourless (like water). They are made using modern severely hydro-treating technology that means treating the oil with hydrogen at high temperatures and pressures in the presence of catalysts. In addition to that, Group III uses isodewaxing which catalytically isomerizes the straight molecular structure of the wax into a branched molecular structure of isoparaffins. These isoparaffins have a high VI, low pour points and excellent resistance to oxidation.

From a performance standpoint, improved purity means that the base oil is more responsive to anti-oxidants in the finished product thus can last much longer. The lubricant is more inert and forms fewer oxidation by-products that increase viscosity and deplete additives. In industrial applications, they are ideal for turbine oils and mineral-based air compressor oils. Their ability to hold additives can be a problem as they might not dissolve additives properly and the additives can drop out of the blend unless an ester, the new PAG or naphthenic oil is added.

In recent years, the paraffinic base oil categories have been informally subdivided, introducing Groups I+, II+ and III+. The new groups fit into the existing Groups I, II and III but their characteristics are close to the top quality levels for each group. As an example, the new gas to liquids base oils (GTL) produced by converting natural gas into synthetic oil, will qualify as Group III+. Discussions have started how to revise the above table.

With regard to Groups IV and V, there are applications where synthetic oil, that are costly, are justified and other applications where they are essential. We will cover this important issue later.

Vegetable oils are biodegradable, have excellent lubricity, high VI and high flash points of more than 300 °C, but they can lack sufficient oxidative stability.

Web

Question 1.9:

1. What requirements must be satisfied to qualify for Group III? ....

1.9.1 What does 'synthetic' mean?

Castrol started using Group III+ base oils in an engine oil and won an advertising watchdog's decision in the USA allowing it to call the engine oil 'synthetic', Mobil lost the case. However, the rest of the world believes that Group II and III base oils are not 'true' synthetic (or semi-synthetic) base oils. In engine oils, it might not make much difference but in compressors true synthetics are definitely better. The question will be covered under various applications.

Web

1.9.2 Polyalphaolefins (PAO)

PAO are the most commonly used synthetic base stocks because of their similarity to mineral base stocks. PAO are in fact synthetic hydrocarbons. Thus they provide excellent miscibility with mineral oils, and good compatibility with paint and seal materials normally used with mineral oils. When using PAO to produce a finished lubricant, there can be a problem of solubility of additives – unless some ester is added to prevent the additives dropping out.

Switching to PAO in old machines might be risky because old seals that are no longer flexible might develop leaks when exposed to PAO. Also, the lubricant might pick up deposits left by the mineral oil thus the machine should be flushed and cleaned (section 1.9.4).

The use of PAO-based gear oils in industrial applications can lead to important savings in energy consumption, as well as decreased downtime and lower maintenance costs. They have a high VI that allows for the use of less viscous oils, which results in greater energy efficiency. Furthermore, their low coefficient of traction reduces internal friction during the normal shearing of an oil film. Energy savings can offset the high price of PAO.

Some of their main attractions are high and low temperature behaviour as well as response to additives. PAO have extremely low pour points. At high temperatures, they evaporate less than mineral oils (low Noack) and have excellent oxidation stability with suitable inhibitors – that means they have an excellent response to additives. Thus they can stand higher temperatures and last longer in service. Thus one application is filled-for-life gearboxes or other equipment that is not easily accessible for oil changes. They are also used in screw-type air compressors.

They also have excellent thermal stability, in other words stability at high temperatures without the presence of air or oxygen.

Due to their purity, several PAO based lubricants have been authorized for use where incidental food contact may occur, so they are often approved as 'food-grade' lubricants.

Web

1.9.3 Other synthetic hydrocarbons

There are other synthetic hydrocarbons used as lubricants or additives. Alkyl benzene is a refrigeration compressor lubricant and polyisobutylene (PIB) is (usually) a very viscous (high viscosity) liquid. It is a polymer (a long chain with repeated structure) with molecular weight of 10 000–50 000. Polyisobutylenes are soluble in other hydrocarbons.

In oil industry, polyisobutylenes are used as additives and thickeners in lubricants. They are particularly suited to replace API Group I bright stock and high viscosity base oils. They might, however, shear (the chain breaks) reducing the viscosity and increasing wear. As additives, they are used to suppress smoke generation, e.g. in 2-stroke engine oils.

Web

Questions 1.9.2:

1. Are PAO hydrocarbons like mineral oils? .... Why? ....
2. List all advantages of PAO ....
....
3. List all disadvantages of PAO ....
....
4. What is the API base stock category for PAO? ....

1.9.4 Switching to PAO

In PAO-based synthetics, a suitable ester is often added to dissolve additives effectively. The additives are soluble in the ester and the ester readily mixes with PAO. The ester can pick up deposits or even lift varnish left by the previous lubricant thus the machine must be flushed thoroughly when switching from another kind of lubricant to either PAO or ester lubricants. Otherwise the picked up old deposits can clog the filters or even oil passages. Even if you flushed the machine, monitor the filters after the switch over.

1.9.5 Polyalkylene glycols (PAG)

Just like PAO, PAG are very popular under extreme conditions, both at high and low temperatures. However, they are very different synthetic lubricants because they are unbranched polymers with molecular weights up to 1500 – and they are polar compounds. That means that one end of the molecule attaches itself to metals etc. and hence they have excellent lubricity and load-carrying ability even without additives. Thus they are ideal for worm gearboxes with worm gears made of phosphor bronze, where they reduce wear and are the best at saving energy.

By their nature, they have not been (until recently, see below) compatible or miscible with mineral oils or PAO. When mixed, e.g. due to insufficient flushing of the system, they formed streaky mixtures. With considerable agitation, these mixtures can thicken into a gel. After using a mineral oil, flush the machine with a light mineral oil to remove solid contaminants and all of the previously used product. It is then important to ensure that none of the flushing oil remains in the machine and then flush with PAG.

A new kind of PAG that is miscible with mineral oils is promoted, so far mainly as an additive.

The best seal materials for use with PAG are Viton (preferred) or Teflon. Use caution with nitrile seal materials as only some have been found satisfactory. High quality epoxy paints are recommended, as polyalkylene glycols tend to attack certain conventional paints. Due to their polar characteristic, most are hygroscopic which means they absorb moisture – this can be a problem. The density of PAG is higher than that of water, thus water does not drop to the bottom of reservoirs.

At extremely high temperatures, PAG evaporate without leaving any deposits. This is an argument used in promoting PAG in turbine oils and compressor oils. They are also clean burning. Some special, and very expensive, air compressor oils are PAG. PAG are commonly used in air conditioning units in cars (it happened because PAG were available before POE).

PAG are not recommended for the lubrication of heavily loaded components made of aluminium or aluminium alloys, e.g. rolling element bearing cages containing aluminium or worm gears made of an aluminium bronze alloy.

Web

1.9.6 Esters

Of greatest importance are diesters, polyol esters (POE, excellent lubricity) and phosphate esters. They will be mentioned again when we deal with lube requirements for various equipment. Diesters are excellent cylinder lubricants for air compressors; polyol esters (and PAG) are used with modern refrigerants such as HFC-134a, and also in gas turbines; and phosphate esters are the best fire-resistant fluids. Most esters are biodegradable.

Web

Questions 1.9.5:

1. List all advantages of PAG ....
....
2. List all disadvantages of PAG ....
3. What synthetics are used in compressors? …...
4. What base oils are biodegradable? …..

1.9.7 Naphthenics

Naphthenic base stocks are much less common. They do not even have their own API base stock category. However, they are essential in some applications, namely in transformer oils. Today's naphthenics are very highly refined (similar to Group II and III oils) thus there is no health hazard in handling them. They have excellent solubility of additives and that makes them useful, at low concentrations, in finished lubricants containing Group III oils, in order to make sure that additives do not drop out of the blend. They also have more natural lubricity than paraffinic oils and more readily emulsify with water.

Because naphthenics are available in lower viscosities than paraffinic stocks, they are also used to produce very light oils. They are also available in higher viscosities than paraffinic Group II and III stocks thus can replace 'Heavy Neutrals' and 'Bright Stock' Group I grades when more and more Group I plants are closing down.

Naphthenics have a low VI and very low pour points. Their low temperature performance made them suitable for refrigeration compressors when Freons were (some still are) used. In low temperature applications, one must consider their viscosity – because of its low VI, the viscosity of a naphthenic oil might be too high at low temperatures.

They were used in reciprocating air compressors before the paraffinic safety compressor oils were developed because of the 'fluffy' (and easy to blow off) deposits they left on the valves.

Web

1.10 Oil performance (additives)

Finished lubricating oils generally contain between 75 and 99% of base stocks, the rest are additives. The combination of base oils and performance additives give the lubricating oil the required performance. Usually, there is one or two requirements that are essential and here the performance additives play a major role. Every application requires a specific combination.

Essential requirements are listed in the following table:

Application	**Essential requirement 1**	**Achieved by**	**Essential requirement 2**	**Achieved by additive**
Automotive engines (3.1+)	Wear protection	Anti-wear additive (3.1, 5.2)	Engine cleanliness	Detergent and dispersant
GF-6B Hydraulics – vane or gear pumps	Wear protection	Anti-wear additive (3.1, 5.2, 10.+)		
Gears – industrial and automotive	Extreme pressure (EP)	EP additive (5.2, 6.)		
Worm gears (6.1)	Lubricity	Lubricity additive *or* base stock (PAG)		
Machine tools (14.)	Lubricity, some EP for gears	Lubricity additive, EP	Tackiness	Tackiness

We will discuss the performance additives as we go along. Your oil supplier will not discuss additives with you. He might not be allowed to do it but also he probably does not know much about it, it's a 'need-to-know' company secret. But he should be able to tell you what base stock types are used and he must know the performance level of his oil.

<u>Web</u>

It is important to remember that there are also basic requirements such as the correct <u>viscosity</u>, low enough <u>pour point</u>, <u>oxidation stability</u>, <u>rust protection</u> (R&O), <u>low foam and air release</u> as well as good <u>water separability</u> (section 1.11) – these characteristics are needed in most lubricating oils.

1.11 Water separability (demulsibility)

There are three main aspects of lubricating oils (base oils, additives and viscosity). Obviously, there are more aspects: pour point etc. Water separability, commonly called 'demulsibility', is another one. This is the ability of an oil to separate from water. It can be determined by a simple method of mixing 40 ml of water with 40 ml of oil, both heated to either 54 °C or 82 °C – and letting the glass container stand. The best result is 40-40-0 in about 10 minutes. That means that all 40 ml of the oil has separated from the water.

A result of 40-37-3 (30) means that, in 30 minutes, the oil has separated but 3 ml of emulsion has appeared between the oil and water. This is the usual acceptable maximum limit. If the result is 35 minutes or 4 ml, the oil is no good – unless it is an automotive engine oil. Automotive engine oils have poor demulsibility. There, we want the water to be carried in the oil until it evaporates in the sump of the engine.

A result of 42-38-0 (15) means no emulsion has formed but 2 ml of water has been absorbed into the oil. This is acceptable in hydraulics but not in rolling bearings! The result has stabilized in 15 minutes. (Refers to the test method ASTM D1401 (for light oils), not D 2711 – see the web pages.)

In big industrial applications, e.g. in turbine oils or big gearboxes, the water should drop to the bottom of the tank and be drained at regular intervals. Demulsifiers are used if the combination of base oils and other additives does not give good results. Some other additives might spoil the demulsibility of the base oils.

Web

Questions 1.10:

1. List some characteristics of naphthenics …..
…..
2. List basic requirements needed in most lubricating oils …...
…...
....
3. What are the performance requirements for automotive engine oils? ....
....
4. When there is a demulsibility requirement, would the result of 39-37-4 (45) be acceptable? ….... Why? (2 reasons) ....

1.12 Supplemental additives

Supplemental ('proprietary') additives are products that are manufactured and marketed as 'add-ons' to automotive engine oils and gear oils. They are meant to improve the frictional characteristics, anti-wear or oxidation resistance of the oils. In the opinion of the major oil companies as well as most manufacturers of equipment, they must <u>not</u> be used.

Anti-wear additives, such as ZDDP (section 3.1), are very effective at separating the underlying surfaces and also strong enough to resist rubbing. But the fact is that when you add such an additive, you have created your own blend and the oil is no longer the oil supplied to you by your lubricant supplier. You are on your own.

Lubricant suppliers pay high prices for additives to the additive manufacturers because the additive manufacturers have to submit their blends to a number of very expensive tests. The blends are carefully balanced to pass all those tests and, of course, during the development of the formulation, they sometimes do not pass them. Every time a formulation changes, the tests have to be run again.

If you add something to the oil, you might improve one characteristic but, at the same time, you are likely to spoil some other performance characteristic. There are times when, in desperation, you might have to improve one characteristic of a lubricant because of some shortcomings of the equipment or unusual operating conditions. When you do that, you have to be aware of the pitfalls.

Web

2. REVISION 1

1. What are the three aspects of every lubricating oil that are good to consider first?

2. How do we achieve the required performance of a lubricating oil?

3. What does “multi-grade 20W-50” tell us about the oil's (a) base oils; (b) performance; and (c) viscosity?

4. List the names of 12 additives mentioned so far.

5. What can be spoilt by a defoamant?

6. What are the old, still commonly used names for mm^2/s and mPa.s?

7. What is the relationship between dynamic and kinematic viscosity?

8. What are the viscosity limits of an ISO VG 460 oil?

9. What are the SAE viscosity grades of engine and gear oils that have viscosities at 100 °C: (a) 10 mm^2/s; and (b) 18 mm^2/s?

10. Which ISO VG grade is close to SAE 90? Hint: Use the viscosity-temperature chart.

11. You need an oil that is 30 mm^2/s at 50 °C. Which ISO VG will you choose?

12. You have an ISO VG 100 gear oil. The equipment manufacturer's (OEM's) requirement is “minimum 40 cSt at the operating temperature”. The operating temperature is 80 °C. Can you use the oil?

13. What does a low viscosity index do to the oil?

14. How do we achieve a high VI? (Mention both methods.)

15. Is an engine oil which has a Noack of 28% good?

16. (a) What does Foam Tendency 150/60/140 mean?
    (b) What does Foam Stability 10/10/10 mean?

17. Is a hydraulic oil which has an air release of 28 minutes good enough?

18. What requirements must be satisfied to qualify for Group II base stock?

19. What are good and bad aspects of PAO?

20. What are good and bad aspects of PAG?

21. Which lubricants are
(a) often approved as 'food-grade' lubricants
and which are (b) biodegradable?

Web

3. AUTOMOTIVE LUBRICATING OILS, ENGINES

3.1 Engine oils

It is often stated that oils lubricating engines have more than one function:-

- **lubrication** – to separate moving parts to prevent wear and reduce friction; to protect engine parts against rust and corrosion; to reduce noise and vibration;
- **cooling** – to remove heat from the hottest parts and areas not otherwise cooled;
- **cleaning** – to remove impurities, to hold them and to carry big particles to the filter;
- **sealing** – to help to prevent blow-by of combustion gases.

Lubrication is achieved by the right oil viscosity and additives.

With automotive engine oils and gear oils, the equipment manufacturer (OEM) tells us what viscosity we should use and what performance level is required.

Equipment manufacturers' viscosity recommendations are, as with most lubricating oils, based on two aspects: the oil must not be (a) too heavy at cold start, and (b) too light at maximum operating temperatures. In many parts of the world, SAE 15W-40 works.

Cleaning is achieved by additives: detergents containing metals prevent high temperature varnish deposits while dispersants keep the particles in suspension. Because of dispersants, automotive engine oils cannot have good demulsibility – the detergents keep moisture in suspension until it evaporates.

These additives, as well as anti-wear, give us the oil's **performance**. A common anti-wear additive is ZDDP (or ZDTP, zinc dithiophosphate). ZDDP adheres to metal surfaces that would act as catalysts in the oxidation process thus ZDDP also reduces oxidation.

As the engine is cleaned by detergents and dispersants, the oil becomes dirty. Thus the oil's darkness in service means that it works! However, there could be so much soot and moisture in the oil (e.g. if a car is used only for short trips when engine never heats up properly) that the oil can no longer hold it. This is the cause of the 'black sludge' that was common just a few years ago. If left unchecked, it could lead to engine oil gelling. The solution is not to exceed drain intervals and to use a good quality oil.

Engine oil needs to be changed before it is saturated with suspended contamination and before it is degraded to the point that it is no longer useful. Today, many companies are beginning to use efficient filtration techniques in combination with high-performance engine oils. This makes it possible to use the oil until it is worn out.

Group I **base oils** are used in many engine oils but their Noack (section 1.6) is often above 15%. When there is a Noack limit, some better base oils must be used. Due to the effort to drastically reduce viscosity of engine oils in order to reduce fuel consumption, lighter base oils are used. Light fractions in conventionally refined (Group I) low viscosity oils vaporize, that means that they have a lower flash point and a higher Noack.

Group I oils will also be unable to meet the extremely low viscosity requirements, for example SAE 0W-12. This will necessitate using synthetic base oils in future.

Finally, some OEM insist on synthetics in their engines.

Web

Questions 3.1:

1. What must an engine oil do in internal combustion engines? 1..
   2..........…....,...................... 3........…..,.......................... 4...
2. Who decides what oil viscosity should be used? …..
3. What are the differences between detergent and dispersant additives? ....
....
4. What are the functions of ZDDP? …..
5. When is Group I base oil suitable in automotive engine oils? …...

3.2 API service categories

The most common way to describe engine oil's performance is the API (American Petroleum Institute) rating. API service categories 'S' are for passenger cars and light trucks using petrol engines (**S**park ignition) and 'C' and 'F' for diesel engines (**C**ompression ignition – **F** means fuel economy). It is possible for some oils to conform to both the petrol and the diesel standards.

For **petrol engines**, API SP, API SN PLUS, API SN, API SM, API SL and API SJ are current. All previous service categories (API SA, SB...SH) are obsolete; there were no API SI and SO.

The new category API SP matches the new ILSAC GF-6A, API SN oils met the obsolete ILSAC GF-5, while API SM oils met the previous ILSAC GF-4. API SM and API SN provide excellent oxidation resistance and deposit and wear protection as well as low temperature performance. The level ofAPI SP ZDDP has been reduced to meet the limit of 0,08% maximum of phosphorus in order to extend the life of catalytic converters. Unfortunately, ZDDP is particularly effective in reducing wear in some old designs of valve trains. API SM was a step backwards to satisfy environmentalists. API SN was then a move in the right direction, actually getting to the root cause of most of the converter problems by setting phosphorous evaporation limits. API SN PLUS provides additional protection against low-speed pre-ignition in turbocharged direct injection engines. API SP now allows fuel saving SAE 0W-8 and 0W-12 viscosity grades.

When the car manual specifies an obsolete API category (e.g. API SF), we may and should use a lubricant with a higher API category (for engines, not for gears). Generally, the higher the category, the better the oil but avoid API SM and API SN for old cars – there API SL is the best.

The current **diesel engine** categories are API FA-4, API CK-4, API CJ-4, API CI-4 PLUS, API CI-4 and API CH-4. All others, e.g. API CC, API CD, API CF-4 and API CG-4 are now obsolete. '4' means 'only four-stroke engines' while '2' meant 'only two-stroke diesel engines' (particularly big Detroit Diesel engines).

The API CI-4 PLUS is a supplemental category developed in response to field problems being reported by major American manufacturers. Introducing API CI-4 to meet the 2002 emission requirements in time, it was virtually impossible to test and work out all of the issues facing the various engine builders with the use of exhaust gas recirculation (EGR).

Mack experienced high soot levels, high viscosity increases at low soot levels, high levels of acid condensate in the intake system and shearing of the engine oil out of viscosity grade in its ASET engines used in severe applications such as refuse and dump trucks. These engines employ the use of internal EGR which allows a certain percentage of the exhaust gases to remain in the cylinder from the previous cycle. This results in the formation of a higher amount and different kind of soot particles that can thicken the engine oil and is more abrasive.

Caterpillar, which uses ACERT technology rather than EGR, experienced higher piston deposits with high ash, high TBN (sections 3.3 and 3.4) API CI-4 formulations. These concerns lead Caterpillar to introduce the CAT ECF-1 specification putting a “cap” on the engine oil’s sulphated ash content and TBN for engine oils that meet the API CI-4 service classification.

Companies that employed the use of EGR responded with their own oil specifications designed to make sure that the engine oils' TBN did not drop below a safe level. Low TBN would rob the engine oil of its ability to provide the proper acid neutralization capabilities to protect the engine from the effect of acidic corrosion. Cummins Engine Company for example revised their CES 20078 specification to place a limit of 10 TBN minimum in order to assure the proper acid neutralization capacity. So API CI-4 needed to be amended and API CI-4 PLUS was introduced.

In order to pass the API CI-4 PLUS supplemental category, the engine oil must pass all of the laboratory bench and engine sequence tests for API CI-4 and also:

1. Pass the Mack T-11 300 hour test or be listed on Mack’s EO-N Premium Plus-03 list.
2. Stay in viscosity grade after 90 passes through the Bosch Injector Shear Test ASTM D-7109. It was found that the normal 30-cycle test is not severe enough to protect engines in the field,

especially under high soot level conditions.
3. Exhibit no greater than a 13% Noack. In addition to environmental considerations, the lower evaporative loss protects the engine from the formation of deposits on critical engine parts.

As usual, there are strict rules about the validity of the test results if other base stocks are used. So a series of extremely expensive laboratory and engine tests are run by additive suppliers in selected base stocks. Oxidation resistance, wear, deposits, foaming, acid formation, sludge control, rust and corrosion protection are tested.

API CJ-4 was specified for American diesel engines in 2010 as a performance improvement over the previous API CI-4 PLUS. Chemical limits have been added in API CJ-4 for new devices in American diesel engines, EGR and the new diesel particulate filter (DPF) to reduce the particulate emissions of diesel engines. Thus sulphated ash (<1,0%) as well as phosphorus (<0,12%) and sulphur (<0,4%) have been limited because these additives could clog the DPF. (Sulphated ash, phosphorus and sulphur are now collectively known as 'SAPS'.)

API CJ-4 oils have a lower TBN (e.g. 8) than previous top quality diesel oils that could have a TBN of e.g. 12. API CJ-4 oils are still suitable for extended drain intervals – provided they are monitored by oil analysis because TBN could drop too much in service.

New tests have been developed for API CK-4 and API FA-4, e.g. Caterpillar C-13 engine oil aeration test; Detroit Diesel scuffing wear test; and Mack T-13 test replaces T- 12 for engine ring and liner wear test. API CK-4 (HTHS viscosity (section 1.2) ≥3.5 mPa.s) and API FA-4 (2.9-3.2 mPa.s – low viscosity for fuel economy) is for use in the new American high-speed four stroke diesel engines meeting 2017 “on-highway greenhouse gas (GHG) emission standards”.

Some engine manufacturers might recommend API FA-4 oils for their previous model-year vehicles while API CK-4 oils will better protect today’s diesel engines than previous standards. However, Ford has not approved the use of API FA-4 oils in its vehicles due to the low viscosity nature of these oils and will approve API CK-4 heavy duty engine oils only if they also meet its WSS-M2C171-F1 specification because, for Ford, API CJ-4 provided better wear protection.

Web

3.3 Sulphated ash test results show the amount of metals in the oil. The metals are in detergents and are effective to combat acids that are generated by sulphur in the fuel. Typical results of sulphated ash are between 0,8 and 1,8%. Detroit Diesel big 2-stroke engines require a sulphated ash of 1,000% maximum to prevent valve deposits that could lead to burnt valves. Caterpillar is also concerned about high sulphated ash (see the previous page).

3.4 The ability of an oil to neutralize acids is expressed as the **Total Base Number** (TBN). A high TBN is achieved by a higher dose of metallic detergents thus sulphated ash is up, too.

Web

Question 3.2:
1. Compare the new API categories: consider backward compatibility; fuel economy; and Ford:
(a) API CK-4 .... (b) API FA-4 ....
2. If phosphorus content is limited, which additive is limited? …...
3. What is 'SAPS'? …..
4. What is the sulphated ash limit for Detroit Diesel big 2-stroke engines? …...........................
5. What TBN was specified for Cummins engines? …...

3.5 ILSAC (International Lubricant Standardization and Approval Committee)

ILSAC **GF-6A** and **GF-6B** specifications are designed to meet the new emissions and fuel economy standards. North American OEMs want all vehicles to use only the latest engine oils. GF-6A is useable in older vehicles as well.

ILSAC GF-6A and GF-6B provide better fuel economy and protection against low-speed pre-ignition, against timing chain wear, against sludge, varnish and high temperature deposits. They protect emission control systems and are suitable for engines using ethanol-containing fuels up to E85. ILSAC GF-6B oils have a viscosity SAE 0W-16 for the best fuel economy.

The previous ILSAC GF-5 could cope with oil temperatures consistently above 100 °C, e.g. in European, Japanese and US cars with turbo-charged engines. It provided better cleanliness and reduced emissions when compared with ILSAC GF-4.

The critical engine test was the Sequence IIIG, which involves running a GM 3.8 litre V-6 engine for 100 hours at 125 horsepower, 3600 rpm, with the oil temperature of 150 °C.

The limits in the Sequence IIIG engine test were:

Kinematic viscosity @ 40 °C increase (due to oil oxidation)	150% maximum
Average weighted piston deposits (controlled by detergents)	merits 4 minimum
Hot stuck rings (controlled by detergents)	None
Average cam plus lifter wear (controlled by anti-wear)	60 μm maximum

(This test was 50% stricter than the test that had been used in ILSAC GF-3 and API SL oils.)

There were other tests. In Sequence VG, sludge and varnish were assessed. In other tests, bearing, piston ring, cam and cam follower wear were measured. Phosphorus had to be 0,06-0,08% and sulphur was limited. Noack was 15% maximum after 1 hour at 250 °C. Rust, high temperature deposits, compatibility with elastomer, foaming and filterability (see Hydraulic fluids) were tested, etc. Allowed viscosities were SAE 0W-xx (e.g. 0W-16), 5W-xx, and 10W-xx.

ILSAC GF-5 became obsolete on 1 May 2021 (a year after the GF-6A and GF-6B introduction).

ILSAC GF-6 requires some new tests. Infineum listed them without giving the limits.

Web

Questions 3.5:

1. How many ILSAC standards are current (in force)? …..
2. Which API category is on the level with ILSAC GF-5? …..
3. Give one example each of cleanliness and wear protection requirements …......................
4. Can SAE 15W-40 and 20W-50 oils satisfy ILSAC requirements? …...................................

3.6 ACEA (Association des Constructeurs Européens d'Automobiles)

ACEA specifications used in Europe are often tougher than the latest API and ILSAC standards but some test results generated for API classifications are accepted.

ACEA categories reflect different performance requirements and a higher number does not mean a higher or more recent specification (unlike API). Some categories are dropped, some are added but most of them are updated at the time of a revision. Thus one should include the year of revision, e.g. ACEA A3/B4-21 (for 2021). A3/B4 is one category with a double name, A is for petrol and B for light duty diesel engines, both of them in passenger cars and small utility vehicles. Class C is for catalyst compatible oils for petrol and light duty diesel engines with after-treatment devices. Class E is for heavy duty diesel engines.

The specifications list laboratory bench tests, methods and limits, e.g. HTHS viscosity (see section 1.2) and SAPS (section 3.2), as well as engine tests. Some tests are meant to solve problems with biodiesel (it promotes oxidation and piston deposits).

A/B: Petrol and light duty diesel engine oils – "High SAPS" (the current categories are **-23** while **- 21** versions may be marketed until the 1st August 2025)

ACEA A3/B4-23 is stable, stay-in-grade engine oil intended for use at extended oil drain intervals in passenger car and light-duty gasoline and direct injection diesel engines.
(Also suitable to replace the obsolete category A3/B3-16) (TBN 10 minimum, full SAPS)

ACEA A5/B5-23 is stable, stay-in-grade engine oil intended for use at extended oil drain intervals in passenger car and light-duty gasoline & DI diesel engines designed for low viscosity engine oils with HTHS viscosity of 2.9 to 3.5 mPa.s. These engine oils are unsuitable for use in certain engines - consult the owner's manual/handbook in case of doubt. (Full SAPS)

ACEA A7/B7-23 is A5/B5 but also provides low speed pre-ignition and wear protection for turbocharged gasoline DI engines as well as turbocharger compressor deposit protection for DI diesel engines

C: TWC (Three-Way Catalyst) and GPF / DPF (Gasoline Particle Filter / Diesel Particle Filter) aftertreatment systems compatible (will increase the DPF/GPF and TWC life), stable, stay-in-grade engine oils intended for use at extended oil drain intervals in passenger car and light-duty gasoline & DI diesel engines and expected to help improve fuel economy (current categories are **-23**)

ACEA C2-23 has mid-SAPS in low viscosity engine oils. (HTHS ≥2.9 mPa.s, Noack 13% max.)

ACEA C3-23 has mid-SAPS, stricter wear and cleanliness requirements
(HTHS ≥3.5 mPa.s, Noack 13% maximum, TBN 6 minimum)

ACEA C4--23 has HTHS and TBN same as C3 but Noack 11% maximum and stricter, that means low-SAPS level: S ≤0.3%, P from 0.07% to 0.09%, sulphated ash ≤0.8%

ACEA C5-23 is for low viscosity oils mid-SAPS level and very low HTHS viscosity 2.6 mPa.s minimum (ideal for SAE 0W- and 5W-20 oils), Noack 13% maximum, TBN 6 minimum)

ACEA C6-23 relative to C5, these oils provide low speed pre-ignition and wear protection for turbocharged petrol DI engines as well as turbocharger compressor deposit (TCCD) protection for modern DI diesel engines. (HTHS 2.6 mPa.s minimum, TBN 4 minimum, Noack 13% max.)

ACEA C7-23 is based on C6 with the exception of enhanced fuel economy
(ideal for SAE 0W-16 oils)

E: Heavy duty diesel engine oils recommended for highly-rated diesel engines meeting Euro I, Euro II, Euro III, Euro IV and Euro V emission requirements; HTHS ≥3.5 mPa.s, Noack ≤13%

ACEA E4-22 provides excellent control of piston cleanliness, wear, soot handling and lubricant stability. It is recommended for engines running under very severe conditions, e.g. significantly extended oil drain intervals according to the manufacturers' recommendations. Suitable for engines without particulate filters as well as for some EGR engines and some engines with SCR NO_X reduction systems. (TBN 12 minimum)

ACEA E8-22 is stay-in-grade oil with similar performance to E4 but suitable for EGR engines (section 3.2), with or without particulate filters, and for engines fitted with SCR NO_X reduction systems. E8 quality is strongly recommended for engines fitted with particulate filters and is designed for use with low sulphur diesel fuel. Thus TBN requirement is reduced to 7 minimum and SAPS is lower (stricter) than in other categories. (ACEA E8 replaces ACEA E6.)

ACEA E7-22 is stay-in-grade oil providing effective control with respect to piston cleanliness and bore polishing. It further provides excellent wear control, soot handling and lubricant stability. It is recommended for engines running under severe conditions, e.g. extended oil drain intervals according to the manufacturers' recommendations. It is suitable for engines without particulate filters and for most EGR engines and most engines fitted with SCR NO_X reduction systems. (TBN 9 minimum)

ACEA E11-22 is stay-in-grade oil with similar performance to E7 suitable for engines without particulate filters and strongly recommended for engines fitted with them. It is designed for use in combination with low-sulphur diesel fuel. (TBN 7 minimum) (ACEA E11 replaces ACEA E9.)

Web

3.7 Equipment manufacturers (OEM)

Some car, truck and off-road vehicle manufacturers have their own specifications and some demand the use of synthetic lubricants. For them, it is a good idea, synthetic base oils are better. But is it really needed? Some OEM have special relationship with oil suppliers.

3.8 What oil to use in car engines

This is what I have found on two labels of engine oil packages (product names deleted):

Hi-Mileage **A guaranteed quality oil** **Viscosity grade: SAE 20W-50**
Benefits: **Thicker oil for reduced consumption**
Compensates for normal ageing
Conditions and rejuvenates oil seals
Better protection against wear
Extends engine life **Meets API SL/CF standards**

Comments from the South African perspective at the time of writing (2018):
This oil has a higher viscosity because 'Hi-Mileage' means high mileage cars (not extended drain); I have an old car and live in moderate climate, good! (This is controversial, not popular today. The concern is slower, possibly inadequate, flow of oil to bearings.)
About their stated benefits: They mean lower oil consumption, not fuel – they should say it. Yes, thicker oil is better for worn parts. (This is controversial, disputed, not popular today, the latest Valvoline products for this application are SAE 5W-20, SAE 5W-30 and SAE 10W-30.)
Maybe they added something for the seals, good! Better wear protection than what???
It is API SL/CF thus it has a good anti-wear. In fact, I would worry if it was API SM or SN because of their lower ZDDP – might not work so well in my old car.
Note that it is not actually approved against API SL/CF but the performance level is there, I trust the company that supplies this oil, they would not risk to misinform.
Summary: When my car was new, API SL did not even exist, now it is still accaptable, so it is good for most cars. I'll buy the oil. I would not buy it if it were API SF or SG.

Advanced Molecular Technology: A premier synthetic lubricant - caters for the demands of new (and older) high performance passenger cars.
WHAT DISTINGUISHES THIS 5W-40 FROM OTHER LUBRICANTS?
Simply this: through its unique, robust and extremely stable molecular structure. Critical research and development has created an oil that is exceedingly durable over all operating conditions.

- **GF-6B Best protection at both high and low speeds**
- **Ideal cold start-up to ensure that every moving part is lubricated**
- **Ideal for use in engines requiring specific oils, like BMW LL 01, MB 229.3 and VW 502**
- **Exceeds all of the latest American Petroleum Institute standards SM**
- **Also suitable for older engines in good condition**
- **Enhanced fuel efficiency**
- **Maximum engine protection**
- **Long-life**
- **Meets global auto specifications and OEM standards**
- **Quality guaranteed**

Comments:
If I had a BMW, I would worry because 'ideal for' does not mean 'meeting' or 'approved', and it is not LL 04. I like the idea of having an API SM oil in my car's engine. As my car is almost new, SAE 5W-40 would be OK. But should I pay extra for a synthetic lubricant? Synthetic oil has better molecules but today's mineral oils are well refined. The synthetic oil will have little influence on the concentration of contaminants in the oil so I will have to change the oil, it will not last forever. When I do, I will be throwing away expensive oil.

Engine oil selection

Follow manufacturer's recommendation! Do not use single grades (SAE 30 or 40). Use heavier oils (20W-50) in older cars, otherwise SAE 15W-40 is fine in moderate climates. Go for a high API, e.g. SL, don't use API SE, SF or SG. Buy a synthetic engine oil only if you have to – or if you have a really exceptional car. For diesel engines, it's the same story: SAE 15W-40 is fine in moderate climates; go for a high API category; follow the OEM recommendations.

The top quality petrol engine oil in 2023 is synthetic, meeting API SP, ACEA C2/C3, BMW LONGLIFE 04 as well as MB 229.31, MB 229.51 and MB229.52.

Other engines

3.9 Two-stroke petrol engines

Different oils are used on land and in outboard motors. In land use, there are different quality levels. In lawnmowers, power tools, small motorcycles and scooters, you can use an ash-free SAE 40 oil pre-diluted to SAE 20 for easier mixing with petrol. The mixing ratio is usually 1:25 (always follow manufacturers' recommendations). These oils can cause engines to smoke.

More expensive oils can be used in the high revving engines of modern motorcycles, chainsaws and generator sets. They meet the old API TC and Japanese JASO FB, FC and FD that have a smoke control test. JASO FD is the highest quality level. In order to reduce smoke, blenders use 1000 molecular weight PIB (section 1.9.3) at 12 to 25%.

They can also be premixed with petrol (if they are SAE 30 then at e.g. 1:50) and used in place of the above mentioned cheaper pre-diluted type.

Semi-synthetic (that could today mean just 10% synthetic) and synthetic two-stroke lubricants meet API TC, JASO and other specifications, e.g. by the Swedish OEM Husqvarna. They are recommended in industrial use, like in the logging industry, but can be used in all applications.

Web

3.10 Outboard engines

In **two-stroke engines**, an oil meeting NMMA (National Marine Manufacturers Association of the USA) TC-W3 should be used. Synthetic oils are sometimes used for environmental reasons because they are biodegradable.

The correct oil for the second lubricated point, the outboard '**Lower Unit Oil**', is usually SAE 80W-90 API GL-4 (section 3.16).

In **four-stroke engines**, FC-W lubricants are required in today's high performance four-stroke engines. FC-W Catalyst Compatible® lubricants meet the catalyst-friendly four-stroke cycle marine engine oil specification that focuses on limiting catalyst poisoning.

Web

3.11 Four-stroke motorcycles can use normal automotive engine oils that do not need to have the top API rating. A higher viscosity, e.g. SAE 20W-50, is recommended. Always follow manufacturers' recommendations, some of them insist on synthetic lubricants. The right product for the compartment that contains a wet clutch should meet the specification JASO MA2 – do not use API SN, SM, or SL there. Castrol claims that its oils “optimise friction” to achieve superior acceleration.

Web

3.12 Gas engines

Petrol engines can burn liquefied petroleum gas (LPG) without much problem and also garbage dump gas, smelter flue gas etc. Because the top parts of the engine can be hotter than when burning petrol, more engine oil is burnt and thus the sulphated ash should be low, e.g. 0,5%, to prevent piston land and ring belt deposits, liner scuffing, and valve seat and valve face wear.

Diesel engines can be converted to liquefied natural gas (LNG) or compressed natural gas (CNG). Then they require dedicated engine oils because they have different combustion systems and after-treatment system requirements compared to diesel engines. Natural gas burns hotter than other hydrocarbon fuels, which puts the engine oil through more severe thermal stress, oxidation and nitration. This may cause the formation of oil sludge and carbon deposits inside the engine. Using natural gas as a fuel may also result in inadequate lubrication of the engine valves, as its cleaner and drier properties produce few carbon particles in the combustion chamber.

Web

3.13 Marine engines and emergency power generation

Some marine engines look like automotive diesel engines but are much bigger. They are called 'trunk piston' engines and are also used inland in emergency power generation. In these engines, one oil is used for both pistons and crankcases.

However, marine engine oils are very different from automotive oils. They are generally single grade SAE 40 or 30 and have a good demulsibility and a very high TBN. The TBN (alkalinity reserve) is generally between 15 and 40 – compare that with a TBN of 10 in automotive engine oils. The purpose of the high TBN is to neutralize acids caused by a high sulphur content in marine fuels. A high sulphated ash – due to a combination of powerful detergents giving the high TBN – is tolerated in these engines.

When marine engines are used inland, automotive diesel fuel is usually used, so there is no need for a high TBN. But there is need for good demulsibility because the engines are designed for that. Even when big automotive-type engines, e.g. Caterpillar 3500 series, Cummins, Volvo, Daihatsu or Yanmar, are used, a special 'high-speed marine diesel engine oil' is recommended with low and moderate sulphur fuels. This oil, unlike other marine engine oils, can be a multigrade 15W-40 with a TBN of 10 and a good demulsibility.

The latest high performance, severe duty engines (MAN-B&W, Alpha, Caterpillar 3600 series, Deutz and Wartsilla) benefit from 'increased dispersancy' engine oils that still have a good demulsibility but also provide reduced liner lacquering, sludge and piston ring groove deposits.

As engines in emergency power generation are often used only during regular test runs of a short duration when they do not reach proper operating temperatures, the engine oil requirements are quite different from other applications. The oil is left in the engines for a long time, is exposed to moisture condensation and must retain its anti-rust inhibition and ability to lubricate from cold start. The moisture can cause gelling of the oil. It is not a bad idea to use a special synthetic marine engine oil in this application – if it's available.

Crosshead-type two-stroke engines are the biggest and are designed for the cheapest, highest sulphur fuel. Pistons are lubricated by 'all-loss' injection of an SAE 50 very high TBN cylinder oil (TBN of 70 or more). Because the crankcase is separate and not directly exposed to the high sulphur fuel, a 'system oil' is used in it. This is a high quality SAE 30 oil with a TBN of 5 or 6 and excellent demulsibility.

Web

3.14 Railroad engine oils are heavy duty, medium speed (1000 rpm) diesel engine crankcase oils. They are high dispersant oils to keep the by-products of combustion and oxidation finely divided and suspended. Sludge build-up due to soot and moisture contamination is minimized. Formulated to suit the main manufacturers of these engines, i.e. General Motors–EMD (Electromotive Division) and General Electric, they are SAE 40 and zinc-free (10 ppm max.) to protect silver bearings and ensure minimum wear of rings, pistons and liners. These engines are big, 187 litres, 4200 HP, and some of them are also in marine use.

The latest EMD, GE and LMOA (the American Locomotive Maintenance Officers Association) specifications require a TBN of only 9 to 10, the previous versions demanded much higher TBN (13 or 17). In all cases, they must have a good alkalinity retention for acid neutralization and wear control.

3.15 Gas turbines

Gas turbines could be industrial type or aviation type. In the latter type, which is more common, aircraft type engines are coupled to generators. The industrial type are specially designed for power generation that have frames, bearings and blades of heavier construction. Aviation type gas turbines use the very expensive aircraft engine lubricants approved by aircraft engine manufacturers. These lubricants are synthetic Polyol ester type, e.g. Mobil Jet Oil 387. The expensive polyphenyl ether lubricant can also be used.

Web

3.16 Automotive gear oils for manual gearboxes and axles

For automotive gear and transmission oils, we do not select the right viscosity by first principles, that means by considering basic machine elements, loads, speeds and operating temperatures. The equipment manufacturer tells you what viscosity you should select (it's the same as with engine oils), and what performance is required. With automotive gear oils, you stick to the required performance level, which is mainly achieved by the correct amount of EP (extreme pressure additive – see 5.2).

Manual gearboxes, particularly synchromesh gearboxes, have traditionally used API GL-4 oils, either SAE 75W, 75W-90, 80W, 80W-90 or 85W-90.

API GL-4 is now formally obsolete because the test equipment is no longer available but is still used because it well describes the performance level (section 5.2).

To meet MAN 341, ZF TE-ML 02A and Mercedes Benz 235.1 specifications, the “correct” percentage of a very specific additive at API GL-4 level must be included in an SAE 80W oil. These oils often have letters 'A' or 'Z' (Shell) in the product name, e.g. Mobilube HD-A 85W-90. ZF is a major German manufacturer of all kinds of transmissions.

Final drives, e.g. rear axles and differentials, and any hypoid gears as well as some manual gearboxes, use API GL-5 oils, either SAE 80W-90, 90 or 85W-140. They are often viewed as multi-purpose as they work well in farm equipment (except wet brakes) and in mining equipment but they should not be used where API GL-3 or GL-4 are specified!

Again, to meet MAN 342, ZF TE-ML 05A and Mercedes Benz 235.0 specifications, the correct percentage of a very specific additive must be included in an SAE 90 oil.

Hypoid gears require a very high level of EP because of the combination of radial and sideways sliding action in the boundary lubrication regime (section 5.2).

Most gear oils use the traditional Group I paraffinic oils but there are also various **synthetic automotive gear lubricants** for extreme conditions or specific requirements of individual equipment manufacturers.

A high VI, **semi-synthetic** SAE 75W-90 oil is used in some Opel, Ford, Nissan and Mazda cars operated under severe conditions at a wide range of ambient temperatures. Elf Tranself NFJ 75W-80 (that has replaced Tranself TRJ) is used by Renault.

Use API GL-3, also obsolete, is now used in Jeep and Mitsubishi manual gearboxes (the latter since 2007) – always check the manuals.

Web

3.17 Limited-slip differentials

In some, we can use API GL-4 oils. More often, specialized API GL-5 limited slip oils contain friction modifiers for extra lubricity and are either SAE 90, SAE 75W/90, SAE 85W/90 or SAE 85W-140.

Informal designations API GL-5+ or API GL-5 LS are sometimes used to describe these oils. ZF (TE-ML-05 – with the very specific additive, of course) and some other OEMs have their own specifications.

Web

Questions 3.16:

1. How do you decide what viscosity (what SAE) you should select? …...................................
2. How do you decide what performance level (what API GL) you should select? …................
3. Should you go for a higher performance level than specified? …..
4. Where do you use heavier oils, in synchromesh gearboxes or in rear axles? ....
5. What API GL level is usually used in limited-slip differential oils? ....
6. What is added to the oil to make it suitable for limited-slip differentials …..............................
7. What letter is used in product names to show that they have the right formulation for ZF? …

3.18 Eaton (formerly Fuller) / ZF-FreedomLine

There are other exceptions where normal gear oils are not used. SAE 50 API CD (now obsolete) engine oils were recommended for some heavy-duty manual transmissions, particularly Fuller, in trucks, buses and off-road equipment. It was the only way to ensure that WRONG gear oils, e.g. API GL-5, were not used.

Today, some oil companies supply specialized SAE 50 synthetic lubricants (not engine oils) for this application. Some of them are approved for 500 000 mile drain intervals. Fuller was taken over by Eaton who now supplies its own Roadranger lubricants. Eleven of these oils are approved for use in ZF-FreedomLine 12- or 16-speed automated two-pedal transmissions in Volvo, Mack and International (Navistar).

According to Eaton, synthetic lubricants protect components better against friction and wear in severe applications such as high loads, and are resistant to oxidation at high operating temperatures. Advanced seal conditioning additives help maintain and extend the life of seals. These lubricants are not suitable for hypoid gears. Examples of approved oils are Shell Spirax GSX SAE 50 (synthetic, Eaton PS-164 Rev. 7, ZF-FreedomLine, Navistar TMS 6816, Mack Truck TO-A-Plus, Volvo I-Shift 120 000 km ODI, API MT-1 – a spec that allows GL-5 level but additional tests are required, e.g. for seals) and Mobil Delvac Synthetic Transmission Fluid 50. Eaton PS-386 specification has now superseded Eaton PS-164 Rev 7.

3.19 Caterpillar TO-4

Caterpillar used to specify the use of API CD (now obsolete) engine oils that also met Caterpillar's TO-2 'Friction Performance Specification' to lubricate 'Powershift' transmissions and final drives. The TO-2 specification ensured good clutch performance with bronze friction discs. The same formulations with just different viscosities were used in hydraulics (SAE 10W), engines and transmissions (SAE 30) and SAE 50 in 'drive trains'. The engine oil SAE 30 could be carried in the vehicle and used for limited top up in other compartments. Multi-grades were then (correctly) not allowed because one should not use multi-grade engine oils in gearboxes**!**

In 1991, Caterpillar made API CD/TO-2 obsolete and replaced it with TO-4. Soon, additional new specifications followed such as Caterpillar FD-1 Final Drive and Axle Oil Specification which, in comparison to TO-4, includes five additional Caterpillar tests but not the 'Friction Performance Specification' for clutch and brake packs. Caterpillar now prefers its own oils supplied by ExxonMobil. For example, Cat TDTO-TMS is a synthetic oil meeting the performance requirements of TO-4M. Commercially available oils must meet the specifications but are not listed as approved and are “second or third choice oils”. To keep up with the tradition, engine oil viscosity grades (SAE 10W, 30, 50 and 60) are still used for gear oils.

Examples of suitable commercial products are Mobiltrans HD 10W, 30 and 50 and Shell Spirax S4 CX 10W, 30, 40, 50 and 60 (also meets Komatsu KES 07.868.1 and ZF TE-ML 03C, 07F).

Web

3.20 Allison

Allison Transmission (Division of General Motors) is the world's largest manufacturer of fully automatic transmissions for medium- and heavy-duty commercial vehicles and is a leader in hybrid-propulsion systems for city buses.

Previously, almost 800 mineral-based engine oils were approved against Allison C-4 specification. Today, Allison C-4 oils are no longer approved for heavy-duty transmissions and there are new specifications in force, against which only a few oils are approved.

Allison recommends that customers use an Allison approved TES 295 automatic transmission synthetic fluid to extend drain intervals and enhance transmission performance and durability in all operating environments with on-highway (road) transmissions. The first approved oil was Castrol TranSynd. Among other approved oils are Mobil Delvac Synthetic ATF and Shell Spirax S6 ATF A295. ExxonMobil followed the tradition and gave its oil, which is unsuitable for engines, an engine oil name. Delvac means Diesel Engine Lubricant Vacuum Oil Company.

An alternative specification, probably not really recommended, is TES 389. Allison approved TES 389 fluids may be used in traditional on-highway (road use) products but do not provide the same drain intervals or filter change intervals as TES 295. TES 389 fluids are selected Dexron III ATFs (see the next chapter). Some time ago, Allison made changes to its transmissions to make them compatible with Dexron III and Dexron VI but Dexron VI synthetic fluids proved to be too light in viscosity in warm climates. Dexron fluids that are not listed are not approved.

The third specification for road use transmissions is TES 468. TES 468 fluids can be used anywhere a TES 295 product is specified and are required in H 40 EP and H 50 EP hybrid propulsion systems for buses. The H 40 EP and H 50 EP series transmissions are equipped with regenerative braking, a system that converts the vehicle’s kinetic energy to stored electric energy when decelerating or stopping. It has proven up to 25% fuel saving over standard diesel buses, depending on the duty cycle. Again, Castrol TranSynd, Shell Spirax S6 ATF A295 and Mobil Delvac Synthetic ATF (plus six other oils) are approved.

Allison recommends only fluids meeting Allison TES 439 specifications for use in 5000, 6000, 8000 and 9000 series off-highway (mainly dump trucks) transmissions. These are basically Allison C-4 fluids but only 13 approved at the time of writing, e.g. Mobil Delvac 1300 Super 15W-40 and Shell Rotella T3, engine oils meeting API CJ-4 and CI-4 PLUS (section 3.2).

Allison's 'only' in the previous paragraph is not strictly correct because there is a new specification, Allison TES-353, against which only one oil has been approved so far: Castrol TranSynd RD TES 353, a premium synthetic automatic transmission fluid. It provides “extended drain intervals and reduced life cycle costs”.

Allison's view about drain intervals is that they should be governed by oil analysis. Periodic samples should be taken from transmissions and sent to a qualified oil analysis laboratory for testing. The critical tests are:

Test	**Limit**
Viscosity	25% change from new fluid
Total Acid Number (TAN)	+3,0 mg KOH/g increase
Water (non-metal contaminant)	0,2% maximum
Ethylene glycol (non-metal contaminant)	0% volume (which means no trace of glycol is allowed – if detected, repair the transmission)
Alien fluids (non-metal contaminants)	0 (if detected, change the fluid)

Additional tests should be:
Other non-metal contaminants: Fuel (% volume)
Soot (% weight)
Metals - Additives and contaminants (ppm): Ba, B, Ca, Mg, P , Si, Na, Zn
Wear metals (ppm): Fe, Cu, Pb, Al
Particle counts (particles/ml oil) at more than 5, >l0, >15, >20, >30, and 40 microns

For best results, analysis should be monitored regularly and results should be analysed consistently to determine trends. (In the writer's opinion, the limits in the table are too loose.)

Web

3.21 Total Acid Number (TAN)

We have already discussed Total Base Number (TBN – section 3.4) that indicates the alkalinity of an engine oil. Total Acid Number (TAN) shows the acidity of oil. It is used to test oil in service. As the oil oxidises, acids are formed. Thus TAN is a good measure of the condition of the oil. It is a laboratory bench method where one determines the number of mg of KOH that is required to neutralize one gram of oil.

Web

3.22 Automatic transmission fluids (ATF)

ATFs are specially formulated light oils (approx. 35 mm^2/s at 40 °C). ATF lubricates, cools, transmits power in a torque converter, transmits pressure in the control hydraulics, inhibits varnish formation and protects the transmission by delaying its own degradation.

There are several different types of ATFs thus they should be used according to the recommendation in the owner’s manual. It used to be simple. Automatic transmissions were used mainly in the USA and there were two types: Dexron II for GM and Type F for Ford (both dyed red). Type F fluids (Ford ESW-M2C 33 G) and Dexron fluids had different frictional characteristics. Mercedes approved some selected Dexron fluids.

Later Ford changed their design and General Motors Dexron III-G was a suitable alternative for the new Ford Mercon, all the previous Dexron III-F, II-E and II-D, GM Type A Suffix A as well as Allison C-4, Mercedes Benz 236.1 and MAN 339. So it was until 2006 when Ford changed the specifications again.

Today, there are separate requirements for GM – synthetic Dexron-VI (since January 2007), Ford – Mercon V and Mercon LV, Chrysler – ATF+4, Honda – DW, ATF T-IV and JWS 3309 – for some Toyota, Volvo, Audi and Volkswagen, Toyota's ATF-WS (World Standard) – for 2004 and later Toyota including hybrids, etc. In addition, there are new designs of transmissions, such as 'Dual Clutch' and CVT (Continuously Variable Transmissions – fluids often dyed green).

The situation is handled differently by Mobil who mainly promotes Mobil Multi-vehicle ATF and Mobil 1 Synthetic ATF (fully synthetic ATF that “outperforms conventional ATFs”) which is also “multi-vehicle”, and Castrol who probably has the widest selection of available fluids:

Castrol Transmax Multivehicle – premium synthetic ATF for Asian vehicles, JWS 3309.
Castrol Transmax FE Multivehicle – fully synthetic ATF for improved fuel efficiency.
Castrol ATF DEX III – Dexron II, Dexron III and Mercon.
Castrol Transmax Dexron-VI Mercon LV – technologically advanced, low viscosity formulation specially designed to deliver maximum fuel efficiency. Also recommended for power steering and meets the Japanese JASO-1A (JASO M315-2003 1A).
Castrol Transmax Z – synthetic ATF for top performance except where Dexron VI is required.
Castrol Transmax Type F – Type F (or G) ATF.
Castrol Transmax Mercon V – ATF for the latest Ford 5-speed transmissions.
Castrol Transmax TQ 95 – ATF for the Australian/Chinese DSI (Drivetrain Systems International, form. BTR Automotive) 4-speed electronically controlled automatic transmissions.
Castrol ATF Heavy Duty – for Volvo Trucks 97341, Allison TES 389, GM Dexron III H, Ford MERCON and Allison C4 specifications.
Castrol Transmax A CVT – fully synthetic, the only CVTF approved for VL300 and VL3800 multitronic (CVT chain) transmissions in Audi A4 (up to 2007 models), Audi A6 and Audi A8.
Castrol Transmax CVT – partially synthetic fluid for use in Japanese push belt CVT.
Castrol Transmax Dual – fully synthetic fluid for the Dual Clutch transmissions.
Castrol Power Steering Fluid – mineral, multifunctional ISO 32-46, SAE 10W-20.

Web

3.23 Farm equipment oils

Farmers do not want to use too many oils because it's so easy to put the wrong oil into a machine. 'Universal Tractor Transmission Oils' (UTTO) are designed for use in transmissions, hydraulic systems, oil immersed ('wet') brakes and other gears (API GL-4, not hypoid) fitted to agricultural equipment. Although individual transmission oil specifications for various farm tractors are quite diverse, UTTO can be successfully used in most of them. 'Super Tractor Oil Universal' (STOU) is for a wide variety of modern agricultural equipment, in most types of diesel and petrol engines (SAE xxW-40) and farm tractor transmission/hydraulic systems including wet brakes, power-shift transmissions, power steering systems, and hydrostatic transmissions.

Web

3.24 Brake fluids

Use DOT 4 or 5.1 fluids (DOT = US Department of Transportation). Brake and clutch fluids should be kept in tightly closed containers to prevent absorption of moisture, preferably using only fluid from sealed containers. Some vehicles require special brake fluids. Many European cars used 'Super DOT 4' that was light yellow in colour. From 2002-2005, they use a low viscosity 'DOT 4 LV' that is also yellow. Some Japanese vehicles still require DOT 3. DOT 5 is a special silicone fluid and must not be mixed with any other fluid.

Web

4. REVISION 2

1. Which oil has a higher viscosity, SAE 50 or ISO VG 68?

2. If a lubricant has a VI of 50, what base oil does it contain?

3. In which applications is anti-wear the key performance additive?

4. Is 25 a typical result for (a) pour point ……... (b) flash point ……... (c) Noack ……...
   (d) air release ………. (e) sulphated ash ……... (f) TBN ……... ?

5. Which of the engine oil specifications, API, ILSAC and ACEA:
   (a) caters for both petrol (gasoline) and diesel engines
   (b) has specific categories for various designs of vehicles
   (c) allows only one valid specification
   (d) introduces new categories, leaving some old ones valid and unchanged
   (e) cancels some and revises all remaining categories
   (f) is the most common world-wide
   (g) is the result of American-Japanese co-operation

6. Is API SE/CC a good oil for modern car engines? ……... and modern truck engines? …......

7. Was API CI-4 a success?

8. What is a good automotive engine oil viscosity in moderate climates?

9. When should you use a synthetic engine oil?

10. Use key word(s) to describe API GL-4 and API GL-5.

11. Is it a good idea to use an API GL-5 oil where API GL-4 is specified?

12. Which manufacturers of heavy equipment do not specify API GL-4 and GL-5?

13. Which viscosity grades are used to describe gear oils in question 11?

14. What could be a moisture (water) limit in an used ATF?

15. Why do we test TAN?

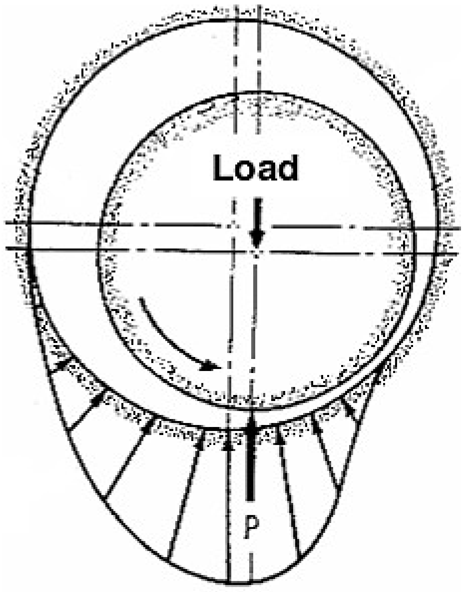
16. What is the latest Dexron and what kind of lubricant does it require?

17. How many ATFs does Castrol have?

18. Can UTTO and STOU be used in (a) engines …...
    (b) hydraulics …........... (c) transmissions …........... (d) hypoid gears? …...........

Web

5. LUBRICATION CONDITIONS



5.1 Hydrodynamic lubrication

When there is enough oil of the right viscosity in a plain bearing, the oil is squeezed into a wedge between the bearing and the rotating shaft and the oil pressure keeps the moving parts separated so they do not touch. Certain minimum speed is needed to form the wedge – otherwise the oil escapes.
In our picture (author unknown), a shaft is turning in the bearing. An oil wedge is formed at the bottom – pressurizing the oil. The relative sizes of the straight arrows drawn in the picture under the bearing indicate how great the pressure is. The shaft can be loaded but the oil pressure prevents it from touching the bearing.

At higher speeds, the pressure is higher and more load can be supported. There is no metal-to-metal contact thus it does not matter what bearing and shaft materials are used. Also, no anti-wear additives in the oil to prevent wear are needed. However, the bearing needs to be properly designed with the correct small clearance – not as in our picture.

This lubrication condition/regime is called hydrodynamic lubrication (or fluid film lubrication) and it happens in plain bearings that are turning and also on some other parts where a wedge can be formed. Under favourable conditions, the oil film can be several microns thick.
Friction is, in this case, entirely due to relative movements of the layers of oil – it is internal friction in the oil. Low viscosity oils cause less friction but cannot support heavy loads. The energy needed to overcome friction is converted into heat. More heat is generated in high viscosity oils.

5.2 Boundary lubrication

Before the shaft starts turning, the two surfaces (the shaft and the bearing) rest on each other. They are separated by a thin layer of oil that cannot prevent microscopic peaks of the two metal surfaces (which are never absolutely smooth) to touch each other.

When the shaft starts turning, the opposing peaks can weld and then chunks of metal can be torn out causing wear of the surfaces and creation of dangerous metal particles floating in the oil. This is called 'adhesive' wear. It is caused by the mutual affinity of surfaces made from the same material. Thus it is better to have different metals touching – they cannot weld. For example, a steel shaft in a white metal bearing – this reduces the friction when the shaft starts turning and prevents wear.

The thin oil layer left on the surfaces does provide some, limited lubrication even if the same metal (e.g. steel) is used on both surfaces. However, wear would occur if the surfaces are not better protected. This lubrication condition is called boundary lubrication. The oil should be fortified at least with a lubricity additive that clings to the surfaces thus supporting sliding motion before the oil wedge is formed. The lubricity additive works on all metals.

When the shaft starts turning but not yet fast enough, that means during the process of forming an effective oil wedge, we have **mixed lubrication**.

When steel is used on both surfaces and an oil wedge cannot prevent metal-to-metal contact because the load is too high or the speed is too low, and a lubricity additive would not be good enough, an anti-wear additive (e.g. ZDDP – see 3.1) is used. This is the case of various parts of engines and hydraulic pumps – vane pumps and gear pumps – as will be mentioned. The anti-wear additive bonds with steel surfaces forming layers that prevent metal-to-metal contact.

When the load is heavy and the rubbing is severe, an anti-wear additive cannot prevent metal-to-metal contact, and extreme pressure (EP) additive is needed. This is the case with gears.

In steel gears, microscopic peaks of both surfaces rub against each other generating very hight temperatures that cause EP additives to react with the surfaces to form iron-sulphide which is soft. So the peaks break into tiny soft pieces that are detached making the surfaces smoother. Thus there is some initial “adhesive” wear on the surfaces but that is much better than if the two surfaces weld to each other, which results in bigger pieces being torn off. The remaining iron-sulphide layers on metal surfaces reduce friction and protect components against shock loading and wear. As the process starts with a chemical reaction at high local temperatures, the lubricant's ability to protect surfaces is sometimes called 'thermal durability'.

The required amount of EP additive depends on application. It is the highest in straight cutting fluids for tough steels (section 14.). In automotive gears, API GL-5 (section 3.16) currently has the highest level because the higher EP level category API GL-6 did not survive, is obsolete and there is no call for it. API GL-4 oils have only one half of the API GL-5 EP level. Exactly one half because that's how it is made. Now you can see that there is a big difference between API GL-4 and API GL-5. The API GL-4 performance cannot be tested so the specification is obsolete but the oils are still made because they are needed. API GL-4 has enough EP to protect gears but not too much to damage bronze parts of the synchromesh. The strong EP additive in API GL-5 oils attacks bronze making it unsuitable for most synchromesh gearboxes but ideal for hypoid gears of automotive rear axles where the rubbing is most severe.

API GL-3, obsolete, is now recommended for some Mitsubishi and Jeep manual transmissions. API GL-3 oils have less EP than API GL-4 and just a bit more than industrial gear oils.

Only non-EP oils are guaranteed to be non-corrosive to copper and other yellow metals that are common in contemporary drive-train systems, that's why Fuller, Eaton, Allison etc. specified engine oils or special fluids for gearboxes and transmissions.

When the load is extreme or there is shock loading or the environment is too hot for normal lubricants, solid additives (particularly moly or graphite) can be used. The sliding layers of moly generate low friction (this can be spoilt by moisture or oxygen) and protect metal surfaces. Moly is used mainly in greases (section 7.7). There are also liquid molybdenum compounds.

5.3 Elasto-hydrodynamic lubrication (EHD or EHL) occurs when the pressure in the wedge is so high that the metals are deformed. This happens because the viscosity of hydrocarbons and many synthetic base stocks increases dramatically with pressure. The metal surfaces are then separated by virtually solid lubricant layer – and deform. No EP or anti-wear additives are needed or desired unless the loads are extreme. This is the case with rolling element bearings. Some manufacturers of rolling element bearings strongly dislike today's EP additives because some EP oils were too aggressive even to the rolling elements made of steel. ZDDP can, in fact, increase friction and wear in EHL conditions.

In spur and helical gears, EHL occurs on each tooth for a fraction of a second when there is pure rolling on the pitch point. Outside the pitch point, there is severe sliding and therefore EP is needed. There is no rolling in worm gears, only sliding, and the bull gear is not made of steel (section 6.1) thus EP is not useful and can attack the material of the gear. Only lubricity is needed.

Web

Questions 5.0:

1. What are the 3 conditions for the formation of an oil wedge? …..
2. Describe all three lubrication conditions …...

....

3. Under what lubrication conditions do rolling element bearings operate? …..........................
4. Under what lubrication conditions do plain bearings operate? …..
5. Under what lubrication conditions do gears operate? …..
6. Mention four different types of additives that help to reduce wear and friction under boundary conditions …...

6. INDUSTRIAL GEAR OILS

Gear oils, both automotive and industrial, are generally EP oils using Group I paraffinic base oils, mostly with Extreme Pressure additives of a sulphur/phosphorus type, oxidation and rust inhibitors and the right amount of defoamants. Also demulsifiers in industrial gear oils to allow moisture to drop out of the oil and be drained regularly from the bottom of the reservoir. So the oils should have good demulsibility (section 1.11), air release and resistance to foaming (1.8).

Because the sulphur in the Extreme Pressure additive can corrode yellow metals, corrosion inhibitors (metal deactivators) are included. In industrial oils, this is done particularly in an effort to protect worm gears as most people do not know that they should not use EP gear oils in worm gearboxes. Friction modifiers are sometimes added for better efficiency.

As we have seen in section 1.5, pour point depressants are also sometimes included. Gear oils supplied by international oil companies are sold all over the world, are manufactured to the same specifications and must be suitable for cold climatic conditions as well as for marine use in ships that travel worldwide.

Industrial gear oils are available in a wide range of viscosities to suit various combinations of speeds, loads and temperatures. For example, Shell Omala S2 G is available in ISO viscosity grades from 68 to 1000. However the most common viscosity for big, well-designed industrial gearboxes is ISO VG 220 and for smaller gearboxes ISO VG 320.

Internationally, the viscosity of industrial gear oils is usually specified in ISO viscosity grades. The American AGMA lubricant numbers/grades (American Gear Manufacturers Association) and David Brown (DB) grades are similar:

ISO VG	68	100	150	220	320	460	680	1000	1500
AGMA No.	2EP	3EP	4EP	5EP	6EP	7EP	8EP	8A EP	9EP
DB Grade	2E	3E	4E	5E	6E	7E	8E	---	---

Shell Omala S2 G is a series of mineral-based oils meeting a number of typical specifications including ISO 12925-1 Type CKD, DIN 51517 Part 3 (CLP), ANSI/AGMA 9005-EO2 (EP), David Brown S1.53.101,102,103,104, US Steel 224 and Cincinnati Machine P34,35,59,63, 74, 76-78. ANSI is the American National Standards Institute. Of the above specifications, the German DIN is the most commonly used world wide. It has three sections:

CLP CC = mineral EP gear oils
CLP HC = synthetic PAO EP lubricants
CLP PG = synthetic PAG lubricants

Among the tests required to meet the specifications are, of course, EP performance tests, particularly FZG. FZG is the preferred EP test because, unlike other EP tests, it uses a pair of gears so it is relevant to gears. The condition of the gears is assessed after every stage of the test. There are 12 stages and the 'fail stage' is reported. With modern industrial EP gear oils, there is no fail stage, oils pass all of them.

Other EP tests quoted are Timken OK Load, and Four-ball EP method, designed by Shell, with results commonly called Weld Load or Seizure Load.

The best EP gear oils also pass the “daunting” Siemens MD specification (formerly Flender) FVA 54 Micro-pitting Load Stage >10 which requires a superior load carrying capacity to prevent micro-pitting (also called grey staining).

For continuous bulk oil temperature above 90 °C, a synthetic lubricant should be considered. Mineral lubricants exposed to high temperatures and air will inevitably oxidise resulting in the formation of lacquer and sludge and inefficient operation due to an excessive increase in viscosity. Synthetic lubricants also oxidise, but, if they have the right additives, much slower than mineral oils.

The service life of mineral-based lubricants is reduced by half, due to oxidation, with every 10 °C above 80 °C operating temperature.

While oil circulation is better than splash lubrication, care must be taken to design it properly. The gears must be flooded with oil but if the oil hits the gear teeth at high pressure, it can generate too much foam. The gears need to be lubricated with oil, not with foam.

Industrial EP gear oils are suitable for spur, helical and bevel gears and can be used in other applications that require EP oils. For hypoid gears, automotive API GL-5 oils should be used. Industrial gear oils are, of course, suitable for bearings in gearboxes although some bearing manufacturers strongly dislike EP oils. Today, EP gear oils are unleaded; the first EP gear oils contained lead – which is an excellent mild EP with cushioning effect but is toxic.

The viscosity selection depends on load, speed and temperature. In multi-stage gearboxes the choice is usually done for the slowest gear set that requires the heaviest oil, unless the selected oil leads to too much churning and consequent overheating.

It has already been explained that, in plain bearings relying on the formation of an oil wedge, higher speeds can support heavier loads. This is true about lubricants generally. Thus at higher speeds, you can use a lighter oil to support the load and prevent metal-to-metal contact. That means that the same viscosity could be correctly selected for a combination of high speed–heavy load as well as for a combination low speed–light load.

Many gearboxes in industrial use are driven by electric motors that run at 1500 rpm. If they are well designed, the gears are big enough to safely support the power that is transmitted (the load). That simplifies the calculation of the required viscosity. Then, as a rule of thumb, the minimum recommended viscosity for a well designed enclosed gear set with spur gears driven by an electric motor and not overloaded or exposed to shock loads is 33 mm^2/s at the operating temperature. The optimum viscosity is 40 mm^2/s at the operating temperature. More involved calculations are done using nomograms or are given on the Internet.

Web

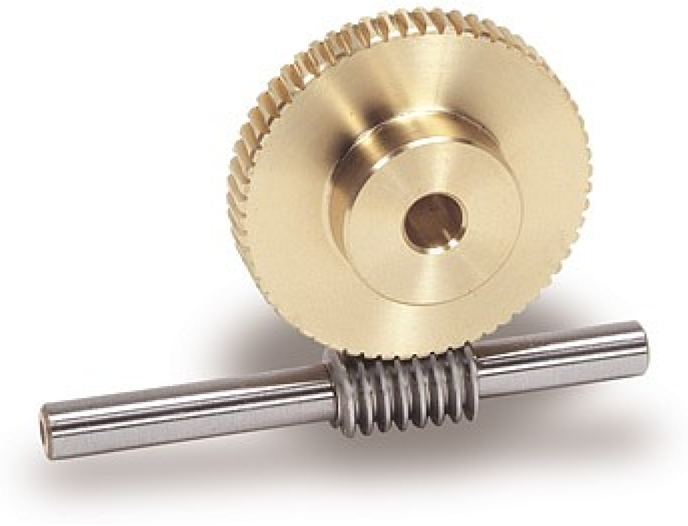
Questions 6.0:

1. What base oils are used in industrial EP gear oils? …...
2. List all additives commonly used in industrial EP gear oils …..
…..
…..
3. Name the most common industrial EP gear oil specification used internationally …..............
4. What is the best EP test for gears and why? …...
5. What happens when the operating temperature in a gearbox increases from 90 to 100 °C?
…..
6. You have two similar well-designed spur gearboxes driven by an electric motor at 1500rpm. One (a) runs at 60 °C and the other (b) at 75 °C. What oil grades should you use in:
(a) .... (b) ....

6.1 Worm gears

It was mentioned that, because sulphur in the Extreme Pressure additive can corrode yellow metals, corrosion inhibitors (metal deactivators) are included in good quality industrial EP gear oils. Thus, in theory, EP gear oils, at least some of them, could be used in worm gearboxes where the critical part is the wheel made of phosphor bronze – this yellow metal is used for its low coefficient of friction. However, it is not a good idea to use EP gear oils in worm gearboxes because there are much better lubricants, namely PAG synthetics, available for this application.

PAG has natural lubricity and that is needed to reduce friction and eliminate wear in worm gears (see below). The old alternative is to use a compounded cylinder oil that contains, typically, 5% of lubricity additive but no EP. Cylinder oils (originally used on the cylinders of steam engines) are available in ISO VG 460 and 1000. This agrees with the rule of thumb that the optimum recommended viscosity for worm gears is 75 mm^2/s at the operating temperature that should not exceed 75 °C with mineral oils. Synthetic lubricants may have a lower viscosity, e.g. ISO VG 220, because of their uniform molecular structure that ensures reliable fluid film and their high VI – thus less viscosity loss with increased temperature.



As mentioned, the currently available PAG lubricants are not compatible or miscible with mineral oils or PAO. When mixed, e.g. due to insufficient flushing of the system when changing to PAG, they form streaky mixtures that can thicken into a gel. New formulations of PAG that are compatible with mineral oils and PAO are being introduced, at first as lubricity/friction modifier additives.

Also, PAG lubricants should not be used with aluminium and aluminium alloys, e.g. with the less common design of steel worm driving an aluminium-bronze wheel.

Web

Questions 6.1:

1. What makes worm gearboxes different from other gears?

....

2. What is the best lubricant for worm gearboxes? …..

6.2 Continuously variable transmissions (small, industrial type)

In CVT, use only the special oil recommended by the equipment manufacturer. There are different types of CVT but for the most common types, to get the right frictional characteristics that ensure proper function and prevent wear, the lubricant should contain aromatic compounds that are not present in normal oils.

6.3 Open gears

These are really big gears where their designers found it too much trouble to enclose them and provide them with an oil circulation system and just decided to rely on very heavy lubricants to cushion excessive loads. This is more understandable when the gears are slow moving but some of them are quite fast, e.g. on pulverizers at some power stations.

Traditionally, these open gears are lubricated with black open gear compounds containing bitumen (that makes them resist water wash-off), other heavy petroleum fractions and some additives (but they can't be too expensive). Some also contain a diluent – non-flammable volatile solvent – for easier application. The diluent quickly evaporates leaving the heavy lubricant behind – until it drops off in an 'all-loss' waste. Old style lubricants without diluent are meant mainly for slush pans where the lubricant is picked up by a slowly turning wheel.

There is a variety of more modern alternatives, without a diluent, some are synthetic or have a tackiness additive. Some of them are greases containing very high viscosity base oils. For example, Shell Malleus GL 3500 is an aluminium complex grease for the temperature range from -7 to 150 °C, NLGI Grade 00 (see the next chapter). Its oil viscosity is 4100 mm^2/s at 40 °C and 157 mm^2/s at 100 °C. It contains an EP additive as well as graphite and moly.

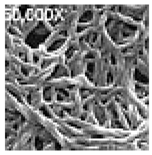
Web

7. GREASES

A grease is a mixture of a liquid lubricant (oil) and a thickener acting like a sponge (see micrograph below) for the oil. Because greases do not flow readily, they are used where extended lubrication is required and oil could not be retained. The thickener can be a 'soap' – a product of a chemical reaction between an alkaline (metallic) hydroxide which gives the grease its name and a fatty acid or ester – or 'non-soap' such as bentonite clay or the more modern polyurea. In addition to the oil and thickener, greases contain additives just like lubricating oils.

When looking at greases, we have to add two more basic aspects to our original three –

1. **Base oil quality** - more important in oils than in greases, mainly mineral in greases
2. **Performance** - particularly if there is EP and moly (or graphite) in the grease
3. **Viscosity!!!**
4. **Thickener** (the 'sponge' that holds the oil) **type** = suitability for the application
5. **Grease consistency** - most greases are NLGI 2 (section 7.3)



The 'consistency' of a grease is its softness or hardness, that means how much the grease resists deformation when pushed.

The original three basic aspects – base oil quality, performance/additives and viscosity – are still important as most experts agree that it is the oil in the grease that lubricates. This is often forgotten. You might have a hard grease and believe that it is suitable for heavy loads. But if the oil in your grease is quite light, the grease is suitable only for light loads – or for high speeds which, for selecting the correct oil viscosity, is the same thing (section 5.1).

A common mistake is to put a multi-purpose EP (EP: sections 5.2, 6.) grease where the oil viscosity could be 150-200 mm^2/s at 40 °C into electric motor bearings where the oil viscosity should be 80 to 100 mm^2/s at 40 °C and preferably no EP. Another mistake is to use this multi-purpose grease where heavy loads require much higher oil viscosity (section 7.7).

Base oils used in greases are mineral, except in special applications such as aviation. Some naphthenic base oil needs to be used in grease production.

Web

7.1 Grease thickeners:

- aluminium complex – multi-purpose, open gears, water resistant, for higher temperatures;
- calcium (lime) – oldest, resistant to water but not necessarily rust inhibiting;
- calcium complex – can absorb water and get softer; for higher temperatures;
- calcium sulphonate – inherent EP/anti-wear and anti-rust, for higher temperatures, water (also salt water) resistance if made of synthetically produced calcium sulphonate;
- lithium 12-hydroxystearate – traditional multi-purpose and motor bearings;
- lithium complex – multi-purpose, stable, good pumpability, for higher temperatures;
- lithium-calcium – retains good aspects of both thickeners, water resistant;
- sodium (soda) – old, fibrous and sticky – not buttery;
- non-soap, e.g. bentonite clay (old); diurea; polyurea (see next) – for high temperatures;
- polyurea – ashless, electric motor bearings, sealed for life bearings, low noise.

7.2 Grease compatibility

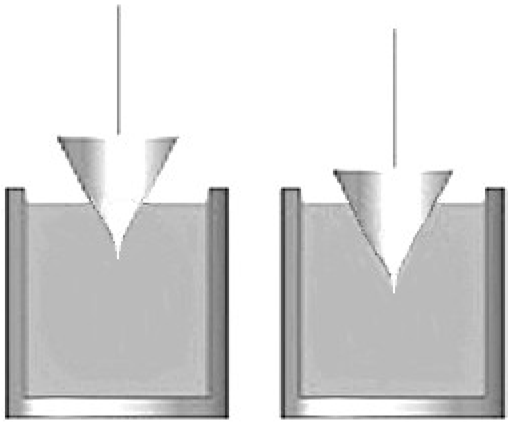
Thickeners are mostly not compatible with each other and the quality of the grease deteriorates badly when they are mixed. Even the same type greases are not safe because, for example, two different polyurea greases might not be compatible. Barium and sodium greases are virtually not compatible with any other greases. It is better not to mix greases even if they are nominally compatible – which is marked C in the following table.

It is also possible to test compatibility using the test method ASTM D6185-1. Drop point is a production test, not user test, but can be used to check compatibility.
(ASTM is the American Society for Testing and Materials – their methods are used world-wide.)

C = compatible	Al compl.	Lime	Ca complex	Ca sulphonate	Li	Li complex	Bentonite	Polyurea
Aluminium complex	C					C		
Calcium (Lime)		C				C	C	
Calcium complex			C	C?		C		C
Calcium sulphonate			C	C	C	C		
Lithium 12-hydroxys.				C	C	C		
Lithium complex	C	C	C	C	C	C		
Bentonite clay		C					C	
Polyurea			C					???

7.3 Grease consistency

The consistency of a grease is its softness (or hardness), that means how much the grease resists deformation. It is measured by 'penetration'.



Normally, the 'worked penetration' method is used: the grease, kept at 25 °C, is first squeezed through small holes 120 times, its surface is then levelled in the container and a metal cone is dropped into it.

In the left picture, the cone did not penetrate too far because the grease was quite hard. In the right picture, the cone penetrated quite deep because the grease was soft.

If the cone has penetrated 28 mm into the grease, the penetration is 28 x 10 = 280. This is a typical result for a multi-purpose grease, NLGI 2 – the grease consistency is reported as NLGI grades (National Lubricating Grease Institute of the USA):

NLGI grade	Worked penetration at 25 °C in 0.1 mm	Description	Application
000	445-475	Fluid	Rock drills
00	400-430	Semi-fluid	Small leaky gearboxes
0	355-385	Very soft	Open gears
1	310-340	Soft	Central lubrication systems
2	265-295	Normal	Multi-purpose, electric motor bearings
3	220-250	Firm	Wheel bearings, high speed
4	175-205	Very firm	
5	130-160	Hard	
6	85-115	Very hard	Block grease (obsolete)

There are gaps between grades because the designers of the table wanted each grease to belong clearly into one or the other grade. Their strategy did not work and ½ grades are often used, e.g. NLGI 2½. For example, the PAO-based aviation grease Mobilgrease 28 thickened with clay is NLGI 1½, its synthetic base oil is very light, 30 mm^2/s at 40 °C. It is suitable for operating temperatures from -54 to 177 °C and has a good anti-wear additive.

The five basic aspects fully describe a grease. Mobilgrease 28's base oil, additive, oil viscosity, thickener and consistency are all given above. An additional information is the maximum operating temperature but that is determined by the base oil, viscosity, thickener type and NLGI.

A traditional multi-purpose grease can be described as mineral-based, EP, ISO VG 150, lithium 12-hydroxystearate, NLGI 2. It replaced old calcium greases (good water resistance) for chassis grease points on cars and trucks and sodium greases (good at high temperatures) for wheel bearings.

Today, more than two thirds of grease volumes produced in the world are lithium but lithium prices are rising because it is also used in batteries. Other thickeners are promoted in multi-purpose and electric motor bearing greases, namely relatively new calcium sulphonate (not all formulations are good) and polyurea. For example, Mobil Polyrex EM and EM 103 are polyurea, NLGI 2 and 3 greases with mineral oil 95 mm^2/s at 40 °C recommended for electric motor bearings as a quiet running grease. These greases are kind to rolling element bearings because they do not contain the EP additive.

Web

7.4 Grease lubricated rolling element bearings

(1) Rolling bearings, with the possible exception of spherical roller thrust bearings, are often lubricated with grease. The lubricating characteristics of grease deteriorate with operating hours forcing re-lubrication of the bearings. Re-lubrication intervals of grease depend on the type, dimensions and speed of the bearing, and on the type of grease.

(2) <u>Do not over-grease!</u> One 'shot of grease' differs but could be about 3 grams. Excessive lubricant causes higher internal friction due to 'churning' that leads to increased temperatures, thus wasted power as well as faster degradation of the grease.

During first assembly or during a complete re-fill, the free space in the housing should be filled only between 1/3 and halfway – unless sealing of the bearing is the main consideration (this exception applies only to low-speed bearings).

(3) Ideally, the old grease should be removed. If the re-lubrication interval is less than 6 months, you can replenish the bearing up to 3 times, and then after 6 months remove all grease from the bearing and re-fill with fresh grease. For the replenishments, the rule of thumb is:

$$Q = 0{,}005\ D.B$$

where Q is the mass of grease in grams to be added into the bearing, D is the outside diameter of the bearing in mm, and B is the width of the bearing in mm.

(4) **Re-lubrication intervals** are specified by the bearing manufacturers in their catalogues. The general rules are:

(a) <u>bigger bearings – shorter interval</u>, e.g. for radial ball bearings at 1500 rpm:
10 mm shaft diameter (d) – 20 000 hours; d = 60 mm – 10 000 hours;
d = 160 mm – 4000 hours; d = 200 mm – 1000 hours.

(b) <u>higher speed – shorter interval</u>, e.g. for radial ball bearings with d = 20 mm:
400 rpm – 30 000 hours; 1500 rpm – 15 000 hours; 5000 rpm – 7000 hours;
10 000 rpm – 2500 hours; 15 000 rpm – only 400 hours.

(c) As mentioned, the above figures are for radial ball bearings. For cylindrical roller bearings and needle bearings, both radial and thrust – halve the intervals.

For taper roller bearings and thrust ball bearings – only 10% of the above intervals.

(d) For severe service involving vibration, shock loading and environmental extremes – 1/3 of the above intervals. Extreme temperatures cut the life of a grease considerably:
If a grease that operates at 80 °C lasts 6 months, then at 100 °C it lasts only 3 months, at 150 °C it lasts 1 month and at 190 °C it lasts only 1 week.

Web

7.5 Typical replenishment instructions for big electric motors

With the power off, clean the grease fittings and immediate area surrounding the grease fittings to prevent contamination of the lubricant. (This instruction is valid generally: always clean the area around the filling or sampling point before opening it.) Open venting ports (relief valves) and probe them to ensure that there is no hardened grease inside.

Using a low pressure grease gun containing the correct type of grease, apply the required amount into the bearing. (Have the amount of grease pumped per stroke measured at the laboratory beforehand. It can vary from about 1 to more than 3 grams.) Stop pumping grease immediately if the lubricant flows out of a venting port or at the shaft.

Do not close the venting port while operating the motor for a short time (it could be 30 minutes or even longer) until the bearing temperature stabilizes. It is normal for bearing temperatures to increase until the grease is evenly distributed throughout the bearing housing. Close the venting ports and all covers and guards that may have been removed to access the equipment.

This information comes from Internet. Rolling element bearing manufacturers provide a lot of information on their web pages. They also provide some calculators which can be used if you know all the details about the bearing and operating conditions.

7.6 Grease-filled gearboxes

Small, slow-speed enclosed gearboxes can also be lubricated by grease. The advantage is that grease cannot leak out as readily as oil through tired or damaged seals. This is particularly important in places where the visibility is poor and thus it is not easy to see the leaks, e.g. in underground mines. The grease also more effectively prevents contaminants entering the gearbox through damaged seals.

Fluid or semi-fluid grease can be used (NLGI grade 00 or 0) but it is better if the grease has thixotropic characteristics, that means it is hard when undisturbed (e.g. when it is sealing) and softer when it is stirred that means when it is lubricating. It should be an EP grease because we are lubricating spur or helical gears. For the same reason, the oil viscosity must be higher, typically ISO VG 320 or 460.

Some synthetic-based semi-fluid (NLGI Grade 00) greases are designed for small industrial gearboxes lubricated for life. Care must be taken in prolonged storage of these gearboxes as the liquid lubricant could separate ('bleed') from the grease and leak out. All greases bleed but some thickeners, particularly complexes, retain the liquid lubricant better than others.

For example, Shell Gadus S5 V142W is a synthetic (PAG), semi-fluid gear lubricant with lithium thickener. Because of PAG, it is not mixable with normal greases containing mineral oils. Mobil has a series of synthetic (PAO) greases of which Mobilith SHC 007 is a lithium complex, NLGI grade 00, ISO VG 460, gear lubricant for operating temperatures from -50 to 150 °C. It is promoted for higher temperatures rather than for gearboxes lubricated for life.
(SHC is Mobil's trade mark meaning 'synthetized hydrocarbon', that means PAO.)

Web

7.7 Grease selection

All five basic aspects must be considered, although the base oil quality is less important than in some other applications because synthetic greases are meant only for special or extreme conditions. The oil's viscosity (chapter 8.) is perhaps the most important aspect and must not be confused with the softness of the grease: it is possible to create an NLGI 2 grease using e.g. ISO VG 100 oil or ISO VG 1000 or any other base oil. One cannot use grease with ISO VG 1000 oil in an application that demands ISO VG 100. The required softness of the grease depends on the application method and speeds. The thickener type is selected according to the operating conditions, particularly the operating temperature and the danger of exposure to water wash. EP is needed for heavy loads. For shock loads, a solid additive, particularly moly (molybdenum disulphide, MoS_2) is often added. Moly provides high lubricity and stability at up to 350 °C, even in oxidizing environments. Try not to use moly in rolling element bearings.

7.8 Grease or oil?

To answer the question “What is better – grease or oil?”, we have to consider the following four points:

1. From a purely lubrication point of view, bearings are better lubricated with oil than with grease provided they are flooded with oil so there is no lubricant starvation.

2. Oil can leak out and be lost leading to lubricant starvation more easily than grease and the grease seals the bearings better against contaminants.

3. Oil lubrication systems are more difficult to design and more costly to make than grease lubrication systems – although there are also other cost factors, e.g. manpower for re-greasing and the price of grease if grease is more costly and more grease than oil is needed.

4. Oil lubrication is needed at very high speeds or when oil must cool the bearings or at extremely high or low temperatures (greases have a seldom quoted “low temperature limit”) or, obviously, when the bearing is part of an oil-lubricated machine, e.g. a gearbox.

Web

Questions 7.0:

1. Name the 5 main aspects that should be considered first regarding greases …..................
....

2. Grease descriptions/types are based on what? ....

3. What does NLGI 2 mean? ....

4. What does “clay thickener, NLGI 1½, oil ISO VG 150, no EP” tell you about a grease and could it be a multi-purpose grease? ....
…..

5. Does the oil ever separate from grease? ....

6. On what kind of gears do we sometimes use grease? ....

7. You have a cylindrical roller bearing on a 55 mm shaft running at 1500 rpm. What could the re-lubrication interval be? ....

8. What conditions must be satisfied to be sure about the answer to question 7?
....

9. If you were to replenish the bearing in question 7, how much grease should you pump into it? (Use your technical feel to estimate your answer.) ....

10. Is the re-lubrication interval longer or shorter with bigger bearings? ....

11. Is the re-lubrication interval longer or shorter with higher speed? ....

12. What is the highest and the lowest oil viscosity in greases given as examples in this book? Give the figures, name the greases and mention the thickeners …........................
....

13. What is still the most popular grease thickener? ....

14. What does ' thixotropic' mean? …..

15. What is better, grease or oil? …....... Why? …...

8. BEARINGS, CIRCULATING OILS

Bearing oils are called circulating oils because some sort of circulation is usually needed to make sure that the bearings are properly lubricated with oil. They must also be suitable for other lubricated parts included in the circulation system. Circulating oils could be R&O (section 1.) oils (e.g. turbine oils) but some also contain anti-wear additives (paper machine oils). Most circulating oils are mineral oil-based.

Some circulating oils are 'general purpose' lubricating oils and for them the same basic formulation is often available in a wide range of viscosities, e.g. from ISO VG 32 to ISO VG 320. The required viscosity depends, of course, on the application, load, speed and operating temperature. The viscosity selection applies to both oils and greases.

8.1 In **rolling element bearings**, where the lubrication condition is EHL (section 5.3), the load has little influence because the viscosity rises with increasing loads and the contact surfaces are enlarged due to elastic deformation. However, small bearings have smaller elements so the contact area is smaller and the pressure can be higher. Also the light oil would escape the small contact area more easily so the viscosity can't be too low.

Unlike the load, speed has a great influence and as the bearing elements move faster in bigger bearings, the viscosity can be lower in big bearings. So it works the same way as the explanation based on the size of the contact area and the pressure (see above). The optimum viscosity of oil for ball bearings at the operating temperature depends on the bearing's mean diameter $d_m = (d+D)/2$ and the running speed:

(a) bigger bearings = lower viscosity, e.g. ball bearings at 1500 rpm:
d_m = 10 mm – 40 mm²/s; d_m = 40 mm – 20 mm²/s; d_m = 60 mm – 15 mm²/s;
d_m = 150 mm – 9 mm²/s; d_m = 300 mm – 7 mm²/s;

(b) higher speed = lower viscosity, e.g. ball bearings with d_m = 100 mm:
200 rpm – 50 mm^2/s; 500 rpm – 25 mm^2/s; 1500 rpm – 11 mm^2/s;
3000 rpm – 8 mm^2/s; 10 000 rpm – 5 mm^2/s;

(c) some manufacturers do not want the viscosity to be lower than 13 mm^2/s;

(d) spherical roller bearings need 50% heavier oil (multiply the above figures by 1.5);

(e) the above viscosities are optimal, minimum viscosity can be lower by about 30%, e.g. instead of 20 mm^2/s optimum, the minimum viscosity could be 13 mm^2/s;

(f) do not use oils with viscosity modifiers (VM, VI improvers) in rolling element bearings because of the behaviour of VM in EHL (thus also do not use them in gears).

Rolling element bearings operate in a variety of conditions that influence their service life. If a bearing fails sooner than at the end of the calculated fatigue life, this bearing may be one of the 10% of all bearings, that, statistically, fail before the full calculated period – or it can be due to some fault in the selection, handling, lubrication or mounting of the bearing.

Or, most often, it could be contamination. Water in bearing oil is particularly dangerous. Rolling element bearings can lose 75 percent of their expected service life due to water in the oil even when the oil contains less than 0.1 percent water, that means before you can see that the oil is becoming cloudy. Thus good oil demulsibility (section 1.11) is required. In proactive maintenance, combating contamination of all kinds is the main focus point.

8.2 The rule of thumb for **plain bearings** -

- the minimum viscosity at the operating temperature is 13 mm^2/s;
- the optimum viscosity at the operating temperature is 30 mm^2/s.

Web

Some circulating oils are designed for specific applications, e.g. extremely light spindle oils (for high speeds, ISO VG 10 or less), or extremely heavy lubricants for journal (plain) bearings of sugar mills (heavy loads, slow speeds, unavoidable contamination), or special oils formulated for Morgan No-Twist mills.

Web

8.3 Paper machines

Paper machines are big and hot. They are lubricated by oil circulated into each bearing and other machine elements. Because of the heat, heavy oil (ISO VG 220 or 320) is used. This creates difficulty, because the heavier the oil, the more difficult it is to protect it against oxidation. In Scandinavia they started using synthetic oils to extend the oil life. Usually, a high quality mineral base oil is used with a good R&O package plus anti-wear – making the oils suitable for moderately loaded gears. Just like some heavier general purpose circulating oils, paper machine oils can contain ZDDP. The oil must have a good air release, good demulsibility to shed water in the reservoir and must not clog filters. It is essential to use a desiccant type breather to stop moisture from air entering the reservoir.

8.4 Steam turbines

The main machine elements that need to be lubricated in turbine-generator sets are plain bearings. When the plain bearings are turning, hydrodynamic lubrication (section 5.1) takes place. When they are not running at normal speed, they should be turning slowly (this is called 'barring') to prevent the shaft sagging. In this case the oil is pumped into the bearings under pressure to lift the shaft – which is called hydrostatic lubrication.

In steam turbines, you usually do not have to worry about the oil viscosity: it is determined by the equipment manufacturer and is likely to be ISO VG 46. For feed pump turbines, ISO VG 32 could be used. The quality of the base oil is most important. It must be the 'turbine quality', which today means Group II or III. The steam turbine oils also have a top class R&O package to allow the oil in the circulating system to last 10 or more years – provided it is continuously filtered and centrifuged and regularly topped up (some oil is removed and used elsewhere). The oil must have a very good air release and very good demulsibility. Modern turbine oils are zinc-free.

In recent years, there has been some attention given to sludge and varnish formation in power station turbine lubricating systems and PAG is promoted to eliminate it. Varnish can be removed or kept under control by various new methods.

For major installations, the turbine oil must meet the requirements and be approved by the equipment manufacturer. For example, Shell Turbo T series is approved against Siemens Power Generation TLV 9013 04 & TLV 9013 05; Alstom Power Turbo-Systems HTGD 90-117; MAN Turbo SP 079984 D0000 E99; Cincinnati P-38 (Turbo T 32); P-55 (Turbo T 46); P-54 (Turbo T 68); and Skoda: Technical Properties Tp 0010P/97. It is also suitable for water turbines and light-duty applications in industrial-type gas turbines that require no enhanced anti-wear performance for the gearbox.

Web

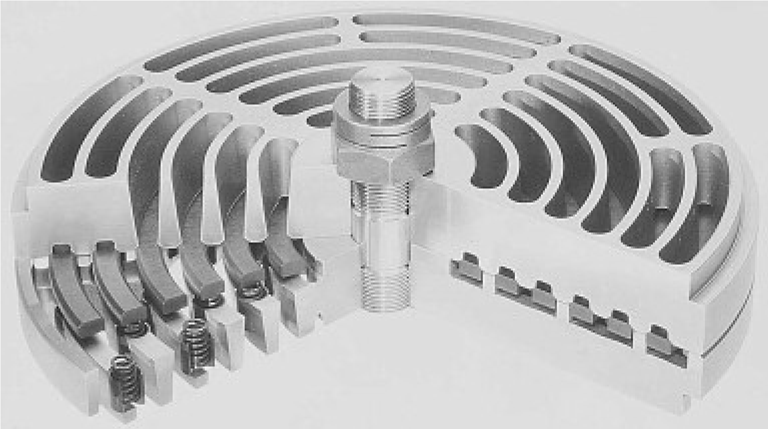
Questions 8.0:

1. What is a circulating oil? ....
2. What viscosities of circulating oils have been mentioned in this manual (both by numbers and in words)? ....
3. What is a turbine oil? ....
4. What does water in oil do to rolling element bearings? …..
5. Is it a good idea to use oils with viscosity modifiers in bearings and gears? …...................

9. COMPRESSORS

9.1 Air compressors

In reciprocating (piston) air compressors, we need to lubricate both the bearings and the cylinders, seal against the blow-by past the piston rings, dissipate heat and protect against corrosion. Just like in engines.



However, compressors have very different valves (the cut in the picture shows how it is designed) and if the oil is allowed to form hard carbon deposits on the exhaust valves, it could lead to a fire or an explosion in the exhaust manifold. In the old days, that was quite common and there were many casualties. After 1970, in order to prevent fires and explosions, specialized 'compressor safety oils' that resist oxidation when exposed to hot air were developed for the cylinder lubrication. Such oils met the German specification DIN 51506 VD-L that was then new but was revised in 1985. The term compressor safety oil is no longer used. Because of the use of the correct cylinder lubricants, fires and explosions due to deposits on the discharge valves are not too common these days. But the danger is still there and the valves need to be inspected regularly.

In single-acting air compressors, one air compressor oil can often satisfy the requirements of both cylinders and bearings, and this oil is fed from the sump either by splash or a circulating system.

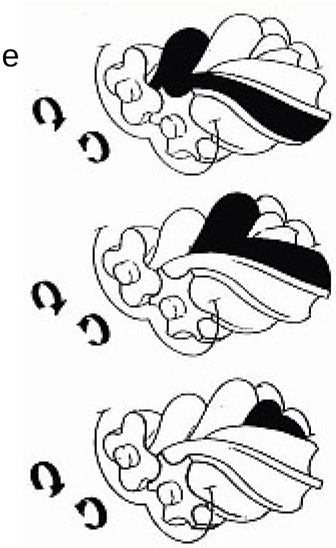
In double-acting compressors there are usually two separate systems: a lighter circulating oil lubricates the crankcase and cross-head bearings, sometimes by means of a gear pump; the other system lubricates the cylinders with a specialized heavier lubricant, typically using a plunger-type pump. Lubrication of the crankcase and cross-head bearings does not present any particular problem since temperatures are normally 60 to 70 °C and, although in splash lubrication a considerable amount of churning takes place, R&O circulating oils give satisfactory service. Of course, air compressor oils can also be used.

In double-acting compressors, the cylinder lubricant must resist oxidation at very high air discharge temperatures thus it has to be a specialized air compressor oil. If the temperatures are well above 180 °C, it is better to use a synthetic lubricant. Diesters are excellent air compressor cylinder lubricants – when formulated with the right additives. Diesters enable the normal valve inspection period, typically between 500 and 1000 hours of operation when using mineral oil-based air compressor oils, to be extended to 2000, or even 4000 hours.

Proper consideration needs to be given to seals when diesters are used. Buna-N with more than 36% acrylonitrile groups is an acceptable material for seals, also fluorinated hydrocarbons, silicone, fluorosilicone, polysulphide, Viton®, and Teflon®. Esters are fully miscible with mineral oils.

The required viscosity depends on the type of compressor and the conditions under which it operates. Compressor manufacturers usually indicate the required viscosity and their recommendation should be followed. In the absence of such directives, the guidelines given below could be used.

Smaller compressors operating at moderate pressures are often lubricated with an ISO VG 68 air compressor oil. If cylinder lubrication is separate, the correct crankcase oil is still ISO VG 68 but the cylinder oil should be heavier, ISO VG 100 or 150. This is because, at the operating temperature, the viscosity should be at least 10 mm^2/s (a rule of thumb).



Manufacturers of rotary screw compressors typically recommend a minimum of 10 mm^2/s and a maximum of 68 mm^2/s for the bearings at the operating temperature, and a minimum of 5 or 10 mm^2/s to lubricate and seal the rotors (see below). This translates to ISO VG 46 as the most common viscosity in rotary screw compressors.

However, there are rotary compressors that require heavier oils, e.g. CompAir Hydrovane rotary vane compressors (traditionally SAE 40 for ambient temperatures between 0 and 40 °C), or Ingersoll Rand's big, high pressure portable screw compressors used in drilling, where only ISO VG 150 synthetic PAO lubricants must be used.

In screw compressors, air is compressed by the meshing action of two contra-rotating helical rotors. The male rotor has lobes that mesh with the flutes on the female rotor. There are fewer male lobes than female flutes thus the male rotor turns faster. At the inlet (which would be situated on the left in the picture), the air fills the void between the rotors and the casing and, as the rotors turn, they squeeze the air axially to the exhaust (on the right). Thus the air is compressed and the engagement between the two rotors prevents it from escaping.

In oil-flooded screw compressors, only one rotor is driven and it drives the other one as in gears. This requires the lubricant (sometimes called 'coolant') that is sprayed inside to mix with the air and lubricate the rotors, to have a good anti-wear or EP properties, to the level of about the fail stage 10 in the FZG test. This is particularly important where the female rotor drives the male rotor. It can be achieved either with the use of ZDDP or zinc-free sulphur-phosphorus additives. As the sulphur-phosphorus additives are gear oil-type EP, they meet the required FZG level easier than ZDDP.

In oil-flooded rotary compressors, proper attention must be given to **coalescer filters** where oil is separated from air and returned to circulation. Compressed air, containing dispersed oil, first passes to a reclaimer where most of the oil falls out as large droplets. The smaller droplets are separated from air by the coalescer filter. In recent years, very fine coalescer filters have been introduced to reduce the oil in compressed air to less than 5 ppm. The obvious environmental benefit is that less oil is discharged into the atmosphere. It also reduces the quantity of oil consumed during the compressor operation. This has, however, reduced the oil top-up which was useful to keep the oil fresh and thus to extend its life. The lubricant must now have a better oxidation stability and its formulation must ensure that the fine coalescer filters are not blocked too quickly. In portable units, under normal conditions, the filter element should be changed every 1000 hours to prevent blockage.

It is always a good idea to use synthetics in oil-flooded screw compressors. PAO and PAG are both excellent. PAG's hygroscopic nature allows it to hold a great amount of water in solution, and not form "free water" as is common with PAOs and mineral oils. This property makes PAGs ideally suited for air compressor applications where there is always moisture present, especially in high humidity environments. Today's advanced PAG formulations can provide up to 16000 hours (2 years) service life between oil changes in air compressor applications, compared to 8000 hours with PAO-based lubricants. The best mineral oils last only 2000 hours. Severely hydrotreated base oils, particularly Group III, are promoted as equal to synthetics but tests show that in severe-service they are not quite as good as PAO or PAG.

If mineral base oils are used in a compressor oil, they must be of the best turbine quality, and the additive package must be top class. The air compressor additive package is different from the turbine oil package because the conditions are different. A turbine oil must last “forever” but it is not exposed to such high temperatures.

Unlike hydraulic fluids or gear oils where products from different respectable oil suppliers meeting the same specifications might in fact be quite similar, air compressor oils are often unique. Each company has developed its own products and their advantages are presented in their literature. No product can outperform others in all aspects but some are better either in the resistance to oxidation; or in FZG rating; or in low tendency to form carbonaceous deposits on valves; or in the ability to prevent the blockage of coalescer filters.

Some major compressor manufacturers have their own expensive lubricants, often synthetic PAG type, and insist that you use them. Examples: Sullair Sullube 32 and Ingersol-Rand SSR Ultra Coolant.

In oil-free screw compressors the two helical rotors do not touch and oil is not sprayed into the air. Both rotors are driven by timing gears to synchronize the meshing of the rotors, thus we must lubricate the gears and bearings like in any other mildly loaded gearbox.

In air compressors for breathing (diving) applications, it is best to use synthetic lubricants tested and approved by the equipment manufacturers.

Web

9.2 Vacuum pumps

The difference between vacuum pumps and compressors is that vacuum pumps exhaust air into the atmosphere in order to produce negative pressure (suction) on the inlet. They require lubricants with the same properties as air compressors but with the additional critical requirement of low vapour pressure, because otherwise the oil vapour might make it impossible to achieve the desired level of vacuum. Use synthetic oils.

Web

9.3 Other gases

PAO are suitable for compressing hydrogen, helium, carbon dioxide and nitrogen, but not hydrocarbons and oxygen. For compressing the natural gas and other hydrocarbons and for process gases use PAG. Only heavily fluorinated lubricants, such as halocarbons, for example polychlorotrifluoroethylene, are safe for avoiding explosions while compressing oxygen.

Web

Questions 9.0:

1. For what application is DIN 51506 VD-L relevant? ....
2. What is the best air compressor cylinder lubricant type? ....
3. What must you watch with reciprocating air compressors to ensure safety of operation? ....
4. What is the recommended viscosity for cylinder lubrication? ....
5. What is the common viscosity for bearing lubrication in piston compressors? …...................
6. Mention some materials of seals suitable for diesters …..
7. At what operating temperature has ISO VG 46 oil viscosity of 10 mm^2/s? …........................
8. What are the two basic types of screw compressors? ....
9. What is the typical oil viscosity grade for oil-flooded screw compressors? …........................
10. What do coalescer filters do? …..
11. What are different oil suppliers striving to achieve? (a) .... (b) ….. (c) ....…............... (d) ....
12. What will happen if you lubricate a high vacuum pump with an ordinary mineral oil? ....
13. What will happen if you lubricate a compressor that compresses oxygen with a mineral oil or PAO? …...

9.4 Refrigeration compressors

The required performance is achieved mainly by the correct type of base stock because additives usually play no role (but see below) and the viscosity in most industrial units is the same: ISO VG 68. In automotive use, the viscosity of PAG depends on the type of compressor.

Refrigerant	Lubricant
Freons: R-12 (CFC) and R-22 (HCFC). The chlorine content of Freons is considered dangerous to the earth's ozone layer thus the last one, R-22, is to be eliminated by the year 2020 (in developing nations by 2030)	Naphthenic oil (keep the containers closed); alkyl benzene (synthetic, compatible with all commonly used sealing materials and miscible with mineral oils, low pour point); PAO for CFC (HCFC only if the installation is designed for efficient separation of oil and refrigerant). Polyol ester (expensive)
Carbon dioxide (R744). CO_2 might replace R-134a in Europe in automotive applications because R-134a is still a greenhouse gas contributing to global warming although less than Freons. The manufacturers of R-134a argue that because using R-134a saves energy, the greenhouse effect is in fact greatly reduced	PAO; PAG recommended by some but not all equipment manufacturers; ExxonMobil recommends its specialized polyol ester, 78 mm^2/s at 40 °C
Non-halogenated hydrocarbons (R600a...)	PAG
Ammonia (R717)	PAO *****; Group II oils; Group III oils (both good); alkyl benzene; PAG ******; naphthenic oil. **Polyol ester (POE) <u>cannot</u> be used! *****
R-134a (HFC). 'Ozone-friendly' chlorine-free hydro-fluorocarbons	PAG (mainly in automotive air conditioning); polyol ester (after opening the container, close it tightly and use within a few days)
Mixtures of HFC with other refrigerants, called 'drop-in' because their characteristics are closer to old refrigerants than R-134a	Polyol ester (POE). (Some plants use mineral oils but doing so is unwise)

***** PAO is recommended for low temperature systems (< -45 °C). Pure PAO is good but PAO usually contains esters and esters cause softening of Neoprene seals thus some systems were switched back to naphthenic oils.

****** PAG is a soluble lubricant for direct expansion systems (no oil separator).

******* Ammonia reacts with polyol ester, breaking it to the original organic acid and alcohol. If water is present, bad! POE is stabilized so that water on its own does not break it in the reaction called hydrolysis (requiring some temperature and pressure).

Mobil AEL Arctic is a polyol ester with a “unique additive system to provide outstanding lubricity, wear protection, chemical and thermal stability and hydrolytic stability”. The product is dried to less than 50 ppm of water and protected by a nitrogen blanket. Available in viscosities from ISO VG 15 to 220. Bitzer B5.2 mixed alkyl benzene lubricant has 39 mm^2/s at 40 °C.

Naphthenic oils could satisfy ISO 6743-3: DRA and DIN 51 503: KAA, KC and KE; alkyl benzene DIN 51 503: KAA and KC; PAO DIN 51 503-1: KAA; and polyol ester DIN 51 503: KD, KE and ISO 6743-3: DRD.

<u>Web</u>

Question 9.4:

1. For which refrigerants are the following lubricants recommended?
   (a) naphthenic oils .... (b) alkyl benzene .... (c) polyol ester ....
   (d) PAG .... (e) PAO ....

10. HYDRAULIC FLUIDS

Hydraulic systems are popular because of their flexibility, reliability, relative simplicity, smaller size and lower cost. They are self-lubricating. Hydraulic oils are commonly called 'hydraulic fluids' because they are, generally, lighter than some other lubricating oils.

In most cases, you should use <u>premium quality anti-wear hydraulic fluids</u>. These fluids meet the German DIN 51524 Part 2 (HLP), ISO 11158-1997 (category HM) and Denison HF-0. To check the quality of a fluid, tests are usually done on an ISO VG 46 sample:

Property	**Typical results/limits**	**How it is achieved**
Kinematic viscosity	46 mm^2/s at 40 °C	Mixture of two suitable base oils
Viscosity index	100	Quality of base oils!
Flash point	214 °C	Quality of base oils!
Water separability	40-40-0 (10)	Quality of base oils, additive should not be needed
Load carrying (FZG)	Fail stage 11	Anti-wear additive!
Foaming stability	Stability 0/0/0 (Tendency 0/0/0 sometimes)	Quality of base oils, additive should not be needed
Air Release at 50 °C	7 minutes	Quality of base oils!
Rust prevention test	Passes both A (distilled water) and B (“sea water”) tests	Quality of base oils plus anti-rust additive
Copper corrosion test	1b	Quality of base oils, additive should not be needed
Inorganic acidity	Nil	Quality of base oils and no bad additives
Neutralization number (NN)	E.g. 0.35 mg KOH/g oil	Depends on the additives; unused oil result is noted for comparing it with results during service life to see if the oil is oxidised
Oxidation stability test	2350 hours to a NN of 2 mg KOH/g oil	Quality of base oils plus oxidation inhibitors
Denison HF-0 test	Passes tests in both types of pumps (piston and vane)	Anti-wear additive!
Anti-wear (Vickers V-104C)	17.6 mg total pump mass loss	Anti-wear additive!
Filterability test (the alternative is Afnor)	Dry 600 s maximum, wet result maximum twice the dry result	Quality of base oils and only good additives used
Hydrolytic stability test	Copper loss 0.12 mg/cm^2	Quality of anti-wear
Seal compatibility tests	Volume and hardness change	The whole formulation

Filterability is measured by sucking clean new oil through a very fine filter which, despite the oil's cleanliness (to be discussed later), gradually gets blocked by a variety of compounds in the oil. The filtration takes much longer if you add some water to the oil.

There are two methods, Denison (see the limits in the above table) and the French Afnor NFE 48-690 (dry) and Afnor NFE 48-691 (wet). In the Afnor 'dry' test, the oil sample goes through the same filter twice and the time it takes are compared – it always takes longer the second time. The time difference is greater if you add the specified amount of water into the oil. That is the 'wet' test. A typical Afnor 'wet' result for a very good oil is 1.1 meaning that the second time it took 1.1 times longer for the oil to get through. This is not an easy test to run.

Denison was an important hydraulic pump manufacturer and their specification HF-0 covered both piston pumps and vane pumps. Denison was taken over by Parker Hannifin so it is now, formally, Parker Hannifin HF-0; HF-1 specification is for piston pumps and HF-2 for vane pumps.

Other common tests are specified by Sundstrand for piston pumps and Eaton Corporation's Vickers for vane pumps.

Conventional solvent-refined paraffinic base stocks (Group I), when fortified with suitable additives, satisfy DIN, ISO and Denison requirements. However, not surprisingly, better base oil formulations are promoted with the promise of vastly increased service life.

The typical viscosities of hydraulic fluids are ISO VG 32, 46 and perhaps 68 but the oils are available in a wider range, e.g. from ISO VG 22 to 100. The right viscosity is selected by juggling two conflicting requirements. This is due to the fact that the oil viscosity reduces rapidly with increasing temperature of the oil – and increases with decreasing temperature of the oil. A hydraulic fluid needs to be light enough at very low starting temperatures in order to be readily sucked into the pump thus preventing cavitation. But it must also be heavy enough at high operating temperatures to prevent wear and internal leakages inside the pump which would result in inefficient operation. But not too heavy otherwise too much heat is generated, it should be less than 50 mm^2/s.

Individual pump manufacturers specify their own requirements but, generally, the oil should not be thicker than 850-1000 mm^2/s (or approx. 750 mPa.s) at the starting temperature, and thinner than 10-13 mm^2/s at the highest operating temperature. The optimum viscosity (rule of thumb) is 25 mm^2/s at the operating temperature.

With high viscosity index fluids the optimum operating range of acceptable viscosities spreads over a wider temperature range and the temperature range for the highest overall efficiency is also wider. Thus you save energy. To make a high VI fluid (with a VI considerable more than 100), the oil company can either use a high VI base oil or viscosity modifiers or both. High VI hydraulic fluids are covered in ISO 11158-1997 (category HV) and DIN 51524 Part 3 (HVLP).

In hydraulic fluids, to be reasonably sheer stable ("stay in grade"), one has to use a very good quality viscosity modifier of a more expensive variety than in engine oils.

National and international standards generally do not specify which anti-wear additive should be used. Environmental concerns, particularly in Europe, are driving the industry toward non-zinc and ashless products in order to remove the heavy metal content. Quite a pity because the zinc additive (ZDDP, section 3.1) is an excellent and relatively inexpensive anti-wear – and a supplementary anti-oxidant. 'Ashless' means that there are no metals at all in the oil.

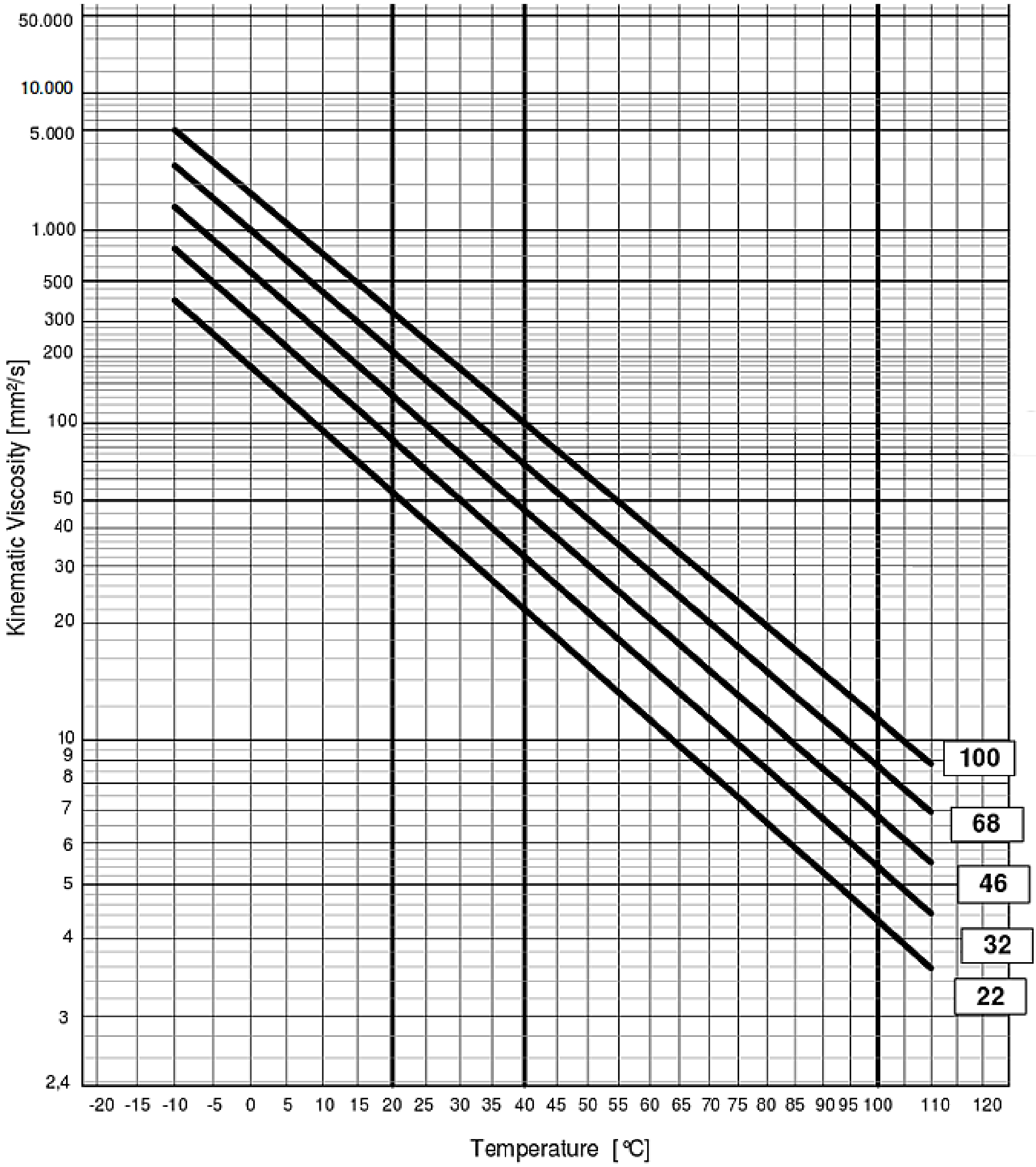
On other continents, zinc and zinc-free formulations are both used. Partial switch to zinc-free formulations happened long time ago because the ZDDP available at that time suffered from hydrolysis (degeneration in the presence of water – see the Hydrolytic stability test in the table). However, zinc was found to be hard to replace to achieve the level of anti-wear performance required by some OEMs, e.g. Denison and Vickers. Modern ZDDP additives (there is a variety of them) are vastly improved, so hydrolysis is no longer a problem – and improved zinc-free, ashless and chlorine-free additives now also fully satisfy all OEMs' requirements.

A major remaining problem is that zinc-containing and zinc-free fluids are generally not compatible. This is because some of the additives in the additive package (not ZDDP itself) react with each other, creating insoluble compounds. Besides the loss of performance due to the loss of additives, the hydraulic system is endangered by filter blocking.

Web

Question 10.0:

1. Which two different types of anti-wear additives are used in hydraulic fluids? …..................



Viscosity-temperature chart (Courtesy Shell South Africa Marketing (Pty) Ltd)

10.1 Fire-resistant fluids

Water is the best fire-resistant fluid. It has been used in hydraulic systems to lift bridges in London since 1882. However, it is not suitable for high performance systems because it tends to evaporate and it supports life: e.g. algae and bacteria. It is also infamous for not protecting steel. Thus the next step is water with suitable additives that would eliminate these problems. High water based fire resistant fluids can be either solutions or emulsions:

Type HF-AS are solutions of various chemicals in water, typically containing anti-rust additives and biocides. They are similar to grinding fluids (chapter 14.).

Type HF-AE are oil-in-water emulsions or micro-emulsions (e.g. 98% water). They are similar to “soluble” cutting fluids. Emulsions are white or off-white and micro-emulsions transparent.

The problem with all HF-A fluids is that most pumps and other hydraulic devices are designed for higher viscosities and HF-A fluids have the same viscosity as water, approx. 1 mm^2/s. To solve that problem, one can increase the fluid viscosity by reducing the water content to about 40% and still maintain good fire-resistance. Two options are popular:

Type HF-B: water-in-oil invert emulsions with a relatively high viscosity of the emulsion – approx. 100 mm^2/s at 40 °C – and off-white colour;

Type HF-C: water-glycol blends where the fluid viscosity (usually 46 mm^2/s at 40 °C) depends on the water content that needs to be regularly checked. A new type of fluid is HFC-E which contains 20% water instead of the usual 35 or more percent in HF-C.

None of the above types is trouble-free in operation and some are difficult in production as well. Synthetic fire-resistant fluids are better but more expensive. There are two types:

Type HF-DR: phosphate esters are the best. Their disadvantage is that they require careful selection of seals and other materials – and an effective highly specialized filtration system.

Type HF-DU: Ordinary synthetic diesters and polyol esters are used because they do not require the same care as phosphate esters but they are not, technically speaking, truly fire-resistant. Your choice will then depend on whether you wish to satisfy some formal regulatory requirements that allow HF-DU or really protect your plant with HF-DR. A new idea is to use PAG which seems to be quite promising.

Web

10.2 Oil cleanliness

Most hydraulic system failures are due to oil contamination. It's been found that improving cleanliness from ISO 21/18 to ISO 14/11 can extend the component life 12 times! Users sometimes demand that the oil company delivers clean oil and even specify how clean the delivered oil should be – e.g. ISO 16/11. Unfortunately, no supplier can guarantee this cleanliness because it is, at least partially, beyond his control – mainly due to the uncertain cleanliness of empty drums. In fact, ISO 16/11 will generally be satisfied by reputable oil suppliers but not each and every drum will necessarily meet it. But then even ISO 16/11 might not be good enough for some equipment, such as some hydraulic systems, if one considers how fine some of the clearances in hydraulic systems are. Also, there is no point in delivering a clean product if the user's own storage and handling practices can lead to oil contamination. There are two ways of solving the problem, not always possible, of course:

(1) fine filtration of the fluid during filling the system with new oil or when topping up;

(2) filling the system and running the pumps for an extended period (e.g. 24 hours) just to filter the oil – that means isolating and not using the rest of the system during that period.

Always continue to filter the oil during normal operation. You cannot see the fine particles that contaminate the oil so you have to test the oil after you set up a cleanliness target. This is a favourite method of pro-active maintenance.

Web

11. LUBRICANT STORAGE

Store lubricants in a clean, dry and cool place. If you must store drums in the open, never store them upright with the bungs on the top because water would get in due to the sucking action: During the day when the oil heats up and expands, excess air is blown out even through tightly sealed bungs! At night, the oil contracts and fresh humid air enters the drum through the bungs. By morning, when the outside air temperature has cooled, the moisture inside the drum will condense and water droplets will fall into the oil. Even worse, if rain water is allowed to cover the bungs of an upright drum, the water will get right in past the sealed bungs. So make sure that the bungs are always under the oil level – that means that the drums are not upright.

Check the oil delivered against the delivery note and against an oil sample kept in a clear bottle.

Use only perfectly clean dispensing equipment.

Check and top up oil in the equipment regularly.

When changing oil in complex pieces of machinery, use a filter cart to add new oil in upstream areas and flush the lines back toward the sump. This is done because the complicated oil supply and return lines will trap particulate matter even when a flushing agent is used. The oil is then drained from the sump, filtered and poured in again until no change is seen between the oil being put into the equipment and the oil being drained from the sump. This removes system contaminants and gives the new oil the best possible starting environment.

It is worth repeating: protect stored lubricants against contamination, heat and moisture.

Web

12. TRANSFORMER OILS

Transformer oil is a very light (9 to 12 mm^2/s at 40 °C), well-refined (to have a good chemical stability and to last 40 years or more) naphthenic oil. Shell has now started promoting its Group III+ GTL oil for this application. In hot climates, where the pour point is not important, paraffinic oils have been used.

One synthetic alternative proved to be disastrous. Polychlorinated biphenyls (PCB) were used many years ago as a dielectric fluid because they are not flammable. PCB does not break down when released into the environment but accumulates in the tissues of plants and animals, where they can have hormone-like effects. When burned, PCB can form highly toxic products. Starting in the early 1970s, production and new uses of PCB have been banned. Esters are sometimes used but the transformers must be designed for their use.

Some products are inhibited against oxidation but that is optional. The main feature of a transformer oil is that it contains very little moisture. To get a breakdown voltage of 70 kV, the oil must have less than 10 ppm of moisture. To meet the minimum specification of 30 kV, it must be less than 30 ppm. In comparison, other mineral oils can contain 100 ppm (0,01%) or more when delivered.

To prevent the oil picking up moisture in storage, transformer oil should not be stored at all! It should be ordered at the right time and, on delivery, immediately put into the equipment, preferably drying it during filling.

Web

13. SHELF LIFE OF LUBRICANTS

Transformer oil must not be stored not because it would go bad but because it might pick up moisture. Mineral oils, when properly stored, would last many years. The author of this book would limit the storage to 5 years, would not store EP oils for more than 2 years, greases for more than a year or maximum two and cutting fluids for 6 months or a year. Implement FIFO – 'first in first out' to ensure that old batches are not left behind. Aviation lubricants have their own strict rules about shelf life.

Web

14. MACHINE TOOLS

Oils designed for machine-tool ways and slides are formulated with selected lubricity additives (first mentioned in section 1.10) to prevent 'stick-slip' (jerky) movement as well as tackiness additives to make them stay on the job – particularly on vertical slides. They have enough EP to be used in gears of machine tools and the ISO VG 68 grade can be used in hydraulic systems of small machine tools as well.

As lubrication of slides is usually “all-loss”, there is no need for base oils better than Group I. There are two main viscosity grades available: ISO VG 68 and 220, the latter for heavy loads and, particularly, for vertical and inclined slide-ways.

Compatibility with cutting fluids, including water based fluids is also important.

Web

15. CUTTING FLUIDS

There are several types of cutting fluids and they can be broadly classified as straight cutting fluids or oils and water-miscible or soluble fluids. Water-miscible fluids are soluble oils (with a high concentration of mineral oil) that form emulsions, synthetics (no oil) and semi-synthetics (up to 30% oil), are now used in approximately 80 to 90 percent of all applications. However, there are some critical metalworking applications reserved for specialized straight cutting oils.

Basic selection depends on whether we need to cool or lubricate. All metal removal processes generate a tremendous amount of heat. This heat must be reduced in order to achieve productivity and machined part quality. The cooling effect provided by a metalworking fluid gives the cutting tool or grinding wheel a longer life and helps to prevent burning and smoking. At the point where the tool is in contact with the part, lubrication is necessary to reduce friction between the tool and the part, resulting in improved tool life and better finishes on the metal cut.

Grinding is a process where you mainly need to cool. You also need to prevent the clogging of the grinding wheel which happens when oil is used. Use a synthetic concentrate that you put into water at a prescribed concentration. Always add the concentrate to water whilst stirring.

In metal cutting you need to know what metals you are going to cut. For tough steel you need a lot of EP in the oil, for yellow metals you need an oil that does not stain the metal. Cutting fluids should protect the machined pieces (and the machine), not to damage it. Metalworking fluids also help remove chips or swarf from the cutting zone.

There is a number of health and environment issues, e.g. eliminating some very effective but dangerous chemicals.

Web

16. RUST PREVENTIVES

Outside the USA, we define 'rust' as the corrosion of iron and steel, keeping the word 'corrosion' for other metals. In the following, we will mention only rust preventives that are related to lubricants (not metal treatment and paints etc.) and that are dedicated to this application (because most oils also provide some protection for metals). There are two kinds:

(1) Rust preventive oils used to fill compartments, such as gearboxes, that are idle for prolonged periods. In this case the product should also generate rust inhibiting vapours to protect steel surfaces above the oil level. An alternative is oil mist where the machine is pressurized with 1 to 3 micron oil droplets in air. The slight pressure is sufficient to exclude contamination while the mist continuously coats the machine’s internal surfaces to prevent rust.

(2) Products sprayed, brushed or applied some other way to metal surfaces. The question is how long the product should be effective – two weeks, 3 months, 6 months, a year? – and, which is related to the protection period, how hard the layer should be, that means should it be 'oily' (e.g. gun oil), 'greasy', 'waxy' or 'hard'. Oily-types should be able to displace water and fingerprint marks and they generally wash off easier but protection is usually limited.

Web

17. REVISION 3

1. Is EHL relevant to worm gears; why? ……………………………………………………………

2. Which gear oils have more EP – automotive or industrial and which type of gears requires the highest EP content? ……………………………………………………………………………

3. What might be the reasons for the instruction: "Never use EP oils in industrial gearboxes which have an internal backstop"? ……………………………………………………………

4. What are the two common viscosity grades for industrial gearboxes and at what operating temperatures do these grades reach the optimum viscosity in a gearbox described in the text? ………………………………………………………………………………………………

5. What alternatives for lubricating open gears do you know? ……………………………………

6. In which aspect(s) are the open gear lubricants unusual? ………………………………………

7. Describe a multi-purpose grease considering all 5 main aspects and explain the significance of each ……………………………………………………………………………………

8. Describe paper machine oils ……………………………………………………………………
………………………………………………………………………………………………

9. What oils are needed for plain bearings, what is the best quality oil of this type, what is this oil's usual viscosity grade and at what operating temperature does this oil reach the optimum viscosity? ………………………………………………………………………………

10. Give three or four typical oil viscosities for various compressors and their parts ....
………………………………………………………………………………………………

11. What is alkyl benzene, where is it used and with what is it compatible and miscible?
………………………………………………………………………………………………

12. What must be done because polyol ester is hygroscopic (readily absorbs moisture)?
………………………………………………………………………………………………

13. Who is the most important hydraulic pump manufacturer – considering its specification which effectively determines if a hydraulic fluid is 'premium quality'? ……………………………

14. What are the highest and lowest viscosity of hydraulic fluids and why? ....
………………………………………………………………………………………………

15. What is the main advantage of using high VI hydraulic fluids? …………………………………

16. Is it a good idea (Yes/No) to use synthetics base stocks in the following applications? If so, exactly in what applications and what synthetics? Can you save energy?

- Automotive engines
- Automotive gears
- Brake fluids for cars
- Worm gears
- Grease applications
- Steam turbines
- Air compressors
- Hydraulics
- Transformers
- Two stroke engines
- Automotive transmissions
- Industrial gears, excluding worm gears
- Open gears and big enclosed gears
- Bearings, excluding turbines and paper machines
- Paper machine oils
- Refrigeration compressors
- Machine tools
- Metal cutting and grinding

Web

18. CHALLENGE

Situation:

Your uncle Vic has a big engineering firm. He does not know much about lubricants but believes he does and is quite proud that he uses only one engine oil and one grease in all applications. He is very handy, so he can fix all problems easily. He particularly likes changing grease-lubricated bearings on electric motors.

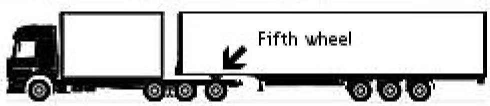
The other day he was grumpy. A customer refused to pay for some parts machined on a lathe because the cut surfaces were not smooth. "It's ugly, I can't use it in my products", said the customer. Now you remember that your uncle told you previously: "It was such a wonderful big lathe when I bought it but now the parts do not move smoothly. I don't know why, I don't see any wear, except in the gearbox, I had to replace some gears. And it makes a lot of noise and smoke when I cut harder metals."

Fortunately, it is summer so Vic can make some money using his big hydraulic press. He does not like to use it in winter because in winter it is too slow, standing out in the open. Also the motor does not want to start in cold weather but he says: "When the bearings get hot, and I mean so hot that you can't touch them, the motor is running fine".

At the moment, Vic is busy opening his big old faithful Broom&Wade piston compressor. He does it every 500 hours to clean the valves. "Once I neglected it and had a fire in the pipe, but it did not explode, it just blew some gaskets", he said. Somebody then advised him to reduce the oil feed to the cylinders. Now the air pressure is not what it used to be. "Maybe the rings are a bit worn."

He loves his old Toyota Cressida and always points out how smooth changing gears is, for the car's age. You cannot say because the differential is so loud. What does he use in the rear axle? "The oil, of course, and I add a handful of grease because the grease has a lot of extreme pressure in it. My father always did it and he did not have such good grease as I have. It has a heavy oil", he says knowingly.

His grease is really special. He does not buy the ordinary multi-purpose grease but the kind used on the fifth wheel of road tractors.



Since a salesman sold him the new 20W-50 multi-grade several years ago, he extended the drain period to 15 thousand km. It works well and oil is clean but he feels that he must flush the engine every time. Also, he has to add a special additive, otherwise the camshaft does not last.

His real worry is the worm gearbox on his mixer. "They don't make the gears the way they used to", he says. Once you brought him a pail of gear oil but it made things even worse.

When he can, he goes to relax on his farm. There is not much water and the wind pump is sluggish. "It turns only in strong wind", he says.

Task:

What advice can you give uncle Vic to solve his problems?

Hint No. 1:

Read the story very carefully. What is going on? And what to do about it? If you are sure of your answers, you can go to Solution (at the end of answers) but it is better to check the other hints first. Hint No. 2 is in answers or in the web page.

Web

ANSWERS

Questions 1.0:

1. *What are the three groups of base oils?* **Paraffinic, naphthenic, synthetic**
2. *Which two groups of base oils are called mineral and why?*

Paraffinic and naphthenic – they come from the ground, from crude oil

3. *What are R&O oils?* **Oils that have only rust and oxidation inhibitor additives**
4. *What do you achieve by having the right viscosity?* **Ability to lubricate**
5. *How does viscosity change with temperature?* **It drops with increasing temperature**

Questions 1.1:

1. *What is a 'heavy' oil?* **Oil having a high viscosity, also called 'thick'**
2. *In measuring what viscosity is gravity involved?*

Kinematic because we measure how fast the oil flows down

3. *At what temperature do we measure the viscosity of industrial lubricating oils?*

40 degrees Centigrade (Celsius)

4. *At what temperature do we measure the viscosity of automotive oils?* **100 °C**
5. *Is ISO VG 68 a typical viscosity for industrial gear oils?*

No, it's too light, typical grades are ISO VG 220 or 320

6. *What are the viscosity limits of an ISO VG 220 oil?* **220 ± 10% = 198 to 242 cSt**

Questions 1.2:

1. *How many engine oil SAE viscosity grades are there?* **14**
2. *Are there maximum kinematic viscosity limits for SAE grades with W?* **No**
3. *Which SAE grades are recently introduced?* **SAE 8, 12, 16**
4. *What is a multi-grade oil?*

An oil that complies with two SAE viscosity grades (one with W and one without W)

5. *Could we have an SAE 30-40 multi-grade?* **No** *Why?*

a) There is no W grade; b) SAE 30 and 40 limits do not overlap

6. *Is CCS relevant to SAE 40?* **No, it is specified only for W grades**

Questions 1.3:

1. *How many automotive gear oil SAE viscosity grades are there?* **11**
2. *Are there gaps or overlaps in KV limits in SAE 80 through 250?* **No**
3. *The test not shown in the table is...* ***S*hear stability test – oil must stay in grade**
4. *Which grades are tested for temperature at which the oil is 150000 mPa.s?* **W grades**
5. *What are the SAE viscosity grades without W of both engine and gear oils having viscosities at 100 °C: (a) 15 mm^2/s* **SAE 40 and 90** *(b) 25 mm^2/s?* **SAE 60 and 140**

Questions 1.5:

1. *What is the name of the additive used to improve pour points?* **Pour point depressant**
2. *Do synthetic and naphthenic base oils have good (low) pour points?* **Yes**

Questions 1.7:

1. *What does a low viscosity index mean?*

The oil's viscosity changes a lot with changing temperature

2. *Does a low viscosity index oil have a steep or not so steep line in the chart?*

The line of a low VI oil in the viscosity-temperature chart is steep

3. *What is the unit of measurement of VI?* **There is no unit of measurement**
4. *You have added values at 70 °C in the above table. Are the values at 70 °C averages of the values at 40 °C and 100 °C (that means exactly in the middle between the values at 40 °C and 100 °C)?*

No. E.g. average of 30 and 5.2 (the last example) is 17.6 cSt but the viscosity at 70 °C is 11.5. Look at the chart how far 11.5 is from 17.6 *Why?* **Because of the log-log scale for viscosity**

Lubricant	Kinematic viscosity (KV), mm^2/s		VI	KV	
	at 40 °C	at 100 °C		at 0 °C	at 70 °C
Synthetic gear oil	230	27.6	155	1500	70
SAE 20W-50 engine oil	135	17.2	139	850	43
Synthetic engine oil	125	22.9	214	520	50
SAE 30 engine oil	100	11.4	102	750	30
Refrigeration compressor oil	55	6.5	65	450	16.6
Hydraulic oil ISO VG 32	30	5.2	102	160	11.5

See the following notes:

NOTES:

a) The viscosity at 40 °C of SAE 20W-50 engine oil will be of interest later.

b) Comparing VI of Synthetic gear oil and Synthetic engine oil (both PAO based), you can see that it is generally more difficult to get a better (higher) VI with heavier (higher viscosity) hydrocarbons. For this reason, SAE 20W-50 engine oil's viscosity at 100 °C is close to the low limit of 16.3 cSt.

c) Refrigeration compressor oil is naphthenic (see 1.9.7). This oil's viscosity is on low side, it should be closer to ISO VG 68. However, in refrigeration it is more important to have a straight cut base oil (just one base oil, not a mixture of two base oils) than the exact viscosity. In refrigeration, the base oil type and quality is the most important aspect (9.4).

Questions 1.8:

1. When should you start worrying about foam on the top of the oil surface

When it spills out of the reservoir or is sucked into circulation

2. What are defoamants and what could they spoil?

Additives that reduce foaming, they can spoil the air release

3. What is a good air release result for ISO VG 46 hydraulic oil? **7 minutes**

4. Two oils (a) and (b) have been tested. Which foam results are ***better*** *and why?*

(a) Foam 180/10;

(b) Foam tendency 190/0/120, foam stability 20/0/0.

This is a trick question: (a) is better because tendency in Sequence I in *a* was 180 (vs. 190 in *b*) and stability 10 in *a* while 20 in *b*. However, test results are technically superior in *b* because Sequences II and III were also run.

Question 1.9:

1. What requirements must be satisfied to qualify for Group III?

Sulphur 0.03% maximum, saturates at least 90% and VI at least 120

Questions 1.9.2:

1. Are PAO hydrocarbons like mineral oils? **Yes** *Why?* **They <u>are</u> hydrocarbons**

2. List all advantages of PAO **High and low temperature performance, excellent response to oxidation inhibitors, energy savings, food-grade suitability, excellent in screw-type air compressors**

3. List all disadvantages of PAO **Price. See also switching to PAO in section 1.9.4 and warning in the chapter about Refrigeration compressors, section 9.4**

4. What is the API base stock category for PAO? **Group IV**

Questions 1.9.5:

1. List all advantages of PAG **High and low temperature performance, considerable energy savings, anti-wear in worm gears with phosphor-bronze bull gears, clean evaporation and burning, superior performance in air compressors**

2. List all disadvantages of PAG **Price. Switching to PAG complicated (until the mixable technology prevails). Hygroscopic. Seals. Concern about aluminium.**

3. What synthetics are used in compressors?

PAO in screw type air compressors, PAG in car air-conditioners and air compressors, diesters in reciprocating air compressors, polyolesters in refrigeration compressors

4. What base oils are biodegradable? **Vegetable oils and esters**

Questions 1.10:

1. List some characteristics of naphthenics **Low VI (bad), low pour point (good), more natural lubricity, more readily emulsify with water and better solubility of additives, availability in lower viscosities**

2. List basic requirements needed in most lubricating oils

The correct viscosity, low enough pour point, oxidation stability and rust protection (R&O), low foam and air release as well as good water separability

3. What are the performance requirements for automotive engine oils? **The main requirements are a) keeping the engine clean and b) preventing wear***....*

4. When there is a demulsibility requirement, would the result of 39-37-4 (45) be acceptable? **No** *Why (2 reasons)?* **Too much emulsion (4, usually 3 max.) and it took too long (45 minutes, usually 30 max.)**

REVISION 1:

1. What are the three aspects of every lubricating oil that are good to consider first?

Base oil quality (e.g. synthetic or not), performance that is specific for each application, and the most important characteristic of a lubricating oil - viscosity

2. How do we achieve the required performance of a lubricating oil?

In some applications, the right base oil is essential, otherwise it is the right additive(s) for each application

3. What does "multi-grade 20W-50" tell us about the oil's
(a) base oils **Nothing**
(b) performance **Nothing**
(c) viscosity? **The oil meets all requirements of both SAE 20W and SAE 50**
4. List the names of 12 additives mentioned so far.
Anti-rust, oxidation inhibitor, viscosity modifier, pour point depressant, defoamant, anti-wear, detergent, dispersant, EP, lubricity, tackiness, demulsifier
5. What can be spoilt by a defoamant? **Air release**
6. What are the old, still commonly used names for mm^2/s and mPa.s?
Centistoke (cSt), centipoise (cP)
7. What is the relationship between dynamic and kinematic viscosity?
Dynamic = Kinematic x Density
8. What are the viscosity limits of an ISO VG 460 oil? **460 – 46 = 414 cSt minimum, 460 + 46 = 506 cSt maximum, at 40 °C**
9. What are the SAE viscosity grades of engine and gear oils that have viscosities at 100 °C:
(a) 10 mm^2/s **SAE 30 and SAE 80**
(b) 18 mm^2/s **SAE 50 and SAE 90**
10. Which ISO VG grade is close to SAE 90? Hint: Use the viscosity-temperature chart.
Use the modified chart from chapter 10 (the last page) and mark the middle value of the new SAE 90, 16 cSt, above 100 °C – you will see that you are close to the line of ISO VG 150; you are assuming that the VI of the SAE 90 oil is normal, around 100, so its line will be parallel to the lines drawn in the chart.
Note: The middle of the old SAE 90 was close to ISO VG 220.
11. You need an oil that is 30 mm^2/s at 50 °C. Which ISO VG will you choose?
In the same chart, find the point 30 cSt at 50 °C (above 50 °C) – you will see that the point is very close to ISO VG 46
12. You have an ISO VG 100 gear oil. The equipment manufacturer's (OEM's) requirement is "minimum 40 cSt at the operating temperature". The operating temperature is 80 °C. Can you use the oil?
In the same chart, find the point 40 cSt at 80 °C (above 80 °C) – you will see that the point is very far from ISO VG 100, you need much heavier oil
13. What does a low viscosity index do to the oil?
It makes the oil's viscosity change a lot with changing temperature
14. How do we achieve a high VI? (Mention both methods.)
Use viscosity modifier additive (previously called VI improver) or a base oil that has a higher VI
15. Is an engine oil which has a Noack of 22% good?
No, but it is a tricky question: in some engines, the oil might be good enough, but in modern engines, 15 % is the usual maximum limit, 13% for API CI-4 PLUS
16. (a) What does Foam Tendency 150/60/140 mean?
Bubbling air through a column of oil heated to 25 °C, the foam level reached the 150 millilitre mark (Sequence I), then the oil was heated to 75 °C and the foam reached 60 ml (Sequence II) and when cooled to 25 °C it was 140 ml (Sequence III)
(b) What does Foam Stability 10/10/10 mean?
After Sequence I, the foam dropped to 10 ml after 10 minutes, it also dropped to 10 ml after 10 minutes after Sequences II and III
17. Is a hydraulic oil which has an air release of 28 minutes good enough?
No, a good figure is 7 minutes for ISO VG 46 hydraulic oil
18. What requirements must be satisfied to qualify for Group II base stock?
Sulphur 0.03% maximum, saturates at least 90% and VI 'normal' that means around 100 or up to 119 (when it would be considered Group II+); note that the VI minimum of 80 is nonsense
19. What are good and bad aspects of PAO? **Well, what are they? (Page 16)**
20. What are good and bad aspects of PAG? **(Page 17)**
21. Which lubricants are
(a) often approved as 'food-grade' lubricants **PAO**
and which are (b) biodegradable? **Esters**

Questions 3.1:

1. What must an engine oil do in internal combustion engines? 1 **Lubricate, which includes protection against rust and corrosion and reducing noise and vibration**
2 **Cool** *3* **Clean** *4* **Seal**
2. Who decides what oil viscosity should be used? **Equipment manufacturers (OEM)**
3. What are the differences between detergent and dispersant additives? **Detergent protects parts against deposits and dispersant keeps contaminants in suspension**
4. What are the functions of ZDDP? **Anti-wear and oxidation inhibitor**
5. When is Group I base oil suitable in automotive engine oils?
When there is no Noack limit and the base oil meets low temperature viscosity requirements and the OEM allows it or the vehicle guarantee has lapsed

Questions 3.2:
1. Compare the new API categories with regard to backward compatibility; fuel economy; and Ford's acceptance:
(a) API CK-4 **compatible; no; yes if also meets Ford's spec.** *(b) API FA-4* **no; yes – improved economy; no**
2. If phosphorus content is limited, which additive is limited? **ZDDP**
3. What is 'SAPS'? **Sulphated ash, phosphorus and sulphur content that is often limited in automotive engine oils for environmental reasons**
4. What is the sulphated ash limit for Detroit Diesel big 2-stroke engines? **1.000%**
5. What TBN was specified for Cummins engines? **10 minimum**

Questions 3.5:
1. How many ILSAC standards are current (in force)? **Only one (unlike API) plus the previous for one year**
2. Which API category is on the level with ILSAC GF-5? **API SN**
3. Give one example each of cleanliness and wear protection requirements
Cleanliness: piston deposits and stuck rings in Sequence IIIG, sludge and varnish in Sequence VG
Wear: cam plus lifter wear in Sequence IIIG, also bearing, piston ring, cam and cam follower wear
4. Can SAE 15W-40 and 20W-50 oils satisfy ILSAC requirements?
No, only SAE 0W-xx (e.g. 0W-16), SAE 5W-xx or SAE 10W-xx are allowed

Questions 3.16:
1. How do you decide what viscosity (what SAE) you should select?
Equipment manufacturer (OEM) tells you – check the manual
2. How do you decide what performance level (what API GL) you should select?
Equipment manufacturer (OEM) tells you – check the manual
3. Should you go for a higher performance level than specified?
No, not with gear oils (with engine oils: yes)
4. Where do you use heavier oils, in synchromesh gearboxes or in rear axles?
Rear axles
5. What API GL level is usually used in limited-slip differential oils? **API GL-5**
6. What is added to the oil to make it suitable for limited-slip differentials
Friction modifiers
7. What letter is used in product names to show that they have the right formulation for ZF? **A, but Shell has started using Z**

REVISION 2:
1. Which oil is heavier, SAE 50 or ISO VG 68? **SAE 50**
2. If a lubricant has a VI of 50, what base oil does it contain? **Naphthenic**
3. In which applications is anti-wear the key performance additive?
Automotive engine oils and hydraulics
4. Is 25 a typical result for (a) pour point **No, should be a multiple of 3**
(b) flash point **No, far too low, typical could be 220 °C**
(c) Noack **No, for applications where it is specified, it is too high (12-15% max.)**
(d) air release **Perhaps but not in hydraulic oils (7 minutes there)**
(e) sulphated ash **Never. In automotive oils around 1, in marine up to 9**
(f) TBN **Not in automotive but in marine oils yes.**
5. Which of the engine oil specifications, API, ILSAC and ACEA:
(a) caters for both petrol (gasoline) and diesel engines **API and ACEA**
(b) has specific categories for various designs of vehicles **ACEA**
(c) allows only one valid specification **ILSAC**
(d) introduces new categories, leaving some old ones valid and unchanged **API**
(e) cancels some and revises all remaining categories **ACEA**
(f) is the most common world-wide **API**
(g) is the result of American-Japanese co-operation **ILSAC**
6. Is API SE/CC a good oil for modern car engines? **No** *and modern truck engines?* **No**
7. Was API CI-4 a success? **No, it was introduced too hastily**
8. What is a good automotive engine oil viscosity in moderate climates? **SAE 15W-40**
9. When should you use a synthetic engine oil?
If you are rich or when you are forced by the manufacturer
10. Use key word(s) to describe API GL-4 **synchromesh**
and API GL-5 **differential, final drive, hypoid**
11. Is it a good idea to use an API GL-5 oil where API GL-4 is specified? **Bad idea**
12. Which manufacturers of heavy equipment do not specify API GL-4 and GL-5?
Eaton and ZF for their FreedomLine, Caterpillar, and Allison
13. Which viscosity grades are used to describe gear oils in question 11?
Engine oil SAE numbers

14. What could be a moisture (water) limit in an used ATF?
0.2% maximum but preferably much less
15. Why do we test TAN? **To see if the oil oxidised**
16. What is the latest Dexron and what kind of lubricant does it require?
Synthetic Dexron-VI (VI means 'six')
17. How many ATF does Castrol have? **12 plus a power steering fluid**
18. Can UTTO and STOU be used in (a) engines **Yes – of farm equipment**
(b) hydraulics **Yes** *(c) transmissions* **Yes** *(d) hypoid gears?* **No**

Questions 5.0:

1. What are the 3 conditions for the formation of an oil wedge? **Enough oil of the right viscosity in a well-designed plain bearing with a shaft turning at a sufficient speed**
2. Describe all three lubrication conditions
Hydrodynamic: an oil wedge is formed in a well designed plain bearing provided there is enough oil of sufficient viscosity and the speed of rotation is also sufficient
Boundary: there is some metal-to-metal contact
EHL: the oil is pressurized so much that it turns almost solid deforming metal surfaces
3. Under what lubrication conditions do rolling element bearings operate? **EHL**
4. Under what lubrication conditions do plain bearings operate? **Hydrodynamic or boundary, mixed during a start up**
5. Under what lubrication conditions do gears operate? **Hypoid: boundary (severe rubbing). Spur and helical gears: EHL for a fraction of a second, otherwise boundary. Worm gears: boundary (sliding)**
6. Mention four different types of additives that help to reduce wear and friction under boundary conditions
Lubricity, anti-wear, EP, solid additives

Questions 6.0:

1. What base oils are used in industrial EP gear oils?
Mineral (paraffinic Group I) unless the operating temperature is more than 90 °C
2. List all additives commonly used in industrial EP gear oils
R&O, EP, defoamant, demulsifier, corrosion inhibitor (metal deactivator), friction modifier, pour point depressant
3. Name the most common industrial EP gear oil specification used internationally
DIN 51517 Part 3 (CLP)
4. What is the best EP test for gears and why?
FZG because it tests wear on gears
5. What happens when the operating temperature in a gearbox increases from 90 to 100 °C?
The service life of mineral-based lubricants is reduced by half
6. You have two similar well-designed spur gearboxes driven by an electric motor at 1500 rpm. One (a) runs at 60 °C and the other (b) at 75 °C. What oil grades should you use? (a) **ISO VG 100** *(b)* **ISO VG 220.**
Hint: In the chart for Tellus S oils in Hydraulics, determine which viscosity grades are close to the points where the 40 cSt line crosses 60 °C and 75 °C lines. (You need the extra lines that you have been instructed to draw in EXERCISE, section 1.7 or see the last page)

Questions 6.1:

1. What makes worm gearboxes different from other gears?
Metals used and the geometry of contact: they do not have steel-on-steel combination and they require lubricity because of the sliding action
2. What is the best lubricant for worm gearboxes? **PAG**

Questions 7.0:

1. Name the 5 main aspects that should be considered first regarding greases
The same three as for liquid lubricants: base oil quality, performance (additives) and the oil viscosity; PLUS the nature of the thickener, and consistency (softness)
2. Grease descriptions/types are based on what?
the nature of the thickener, if it's a soap then the metal(s), e.g. 'calcium grease'
3. What does NLGI 2 mean?
It means consistency of a soft grease: in the worked penetration test, the result was between 265 and 295 tenths of millimetre
4. What does "clay thickener, NLGI 1½, oil ISO VG 150, no EP" tell you about a grease and could it be a multi-purpose grease?
A grease designed to stand high temperatures (clay), very soft (NLGI), suitable for speeds that would depend on the operating temperature (ISO VG 150), not fortified for heavy and shock loads. It's not a MP grease, because the thickener is wrong, it is too soft and it does not have the required EP additive

5. Does the oil ever separate from grease?
It must – to be able to lubricate, it's called bleeding, you'll find a puddle of oil on the top of grease in storage = no problem but you can't mix it back into the grease
6. On what kind of gears do we sometimes use grease?
Open (big) gears and small leaky gearboxes
7. You have a cylindrical roller bearing on a 55 mm shaft running at 1500 rpm. What could the re-lubrication interval be?
55 is close to 60, if it was a radial ball bearing, the interval would be say 11 000 hours; for a cylindrical roller bearing, it is one half thus 5500 hours
8. What conditions must be satisfied to be sure about the answer to question 7?
There is no vibration, shock loading and environmental extremes
9. If you were to replenish the bearing in question 7, how much grease should you pump into it? (Use your technical feel to estimate your answer.)
To make the calculation simple, let's assume that the bearing's outside diameter is 100 mm and the width 25 mm, then 0.005 x 100 x 25 = 12 grams
10. Is the re-lubrication interval longer or shorter with bigger bearings? **Shorter**
11. Is the re-lubrication interval longer or shorter with higher speed? **Shorter**
12. What is the highest and the lowest oil viscosity in greases given as examples in this manual? Give the figures, name the greases and mention the thickeners
30 cSt at 40 °C in clay-based Mobilgrease 28, 4100 cSt at 40 °C in aluminium complex open-gear grease Shell Malleus GL 3500
13. What is still the most popular grease thickener? **Lithium**
14. What does ' thixotropic' mean? **The grease is harder when undisturbed (e.g. when it is sealing) and softer when stirred (when lubricating)**
15. What is better, grease or oil? Why? **Oil is definitely better for lubrication and it is necessary for extreme conditions, but grease is needed when the equipment is not designed for oil lubrication and when the lubricant must stay on the job and instead of falling off**

Questions 8.0:
1. What is a circulating oil?
An oil for bearings and other suitable lubricated parts included in the circulation, “general purpose” oil
2. What viscosities of circulating oils have been mentioned in this manual (both by numbers and in words)?
Spindle oils ISO VG 10, turbine oils ISO VG 46, paper machine oils ISO VG 320, extremely heavy oils (much more than 1000 cSt at 40 °C) for plain bearings in sugar mills. Recommended viscosities, e.g. 13 cSt minimum at the operating temperature
3. What is a turbine oil? **A very high quality R&O oil**
4. What does water in oil do to rolling element bearings? **Destroys them**
5. Is it a good idea to use oils with viscosity modifiers in bearings and gears? **No**

Questions 9.0:
1. For what application is DIN 51506 VDL relevant?
Cylinder lubrication of reciprocating (piston) air compressors with very high air temperatures
2. What is the best air compressor cylinder lubricant type? **Diester**
3. What must you watch with reciprocating compressors to ensure safety of operation?
Valves need to be regularly inspected and cleaned if necessary
4. What is the recommended viscosity for cylinder lubrication? **ISO VG 100 or 150**
5. What is the common viscosity for bearing lubrication in piston compressors?
ISO VG 68
6. Mention some materials of seals suitable for diesters
Viton, Teflon, fluorinated hydrocarbons, silicone, fluorosilicone, polysulphide and Buna-N with more than 36% acrylonitrile groups
7. At what operating temperature has ISO VG 46 oil viscosity of 10 mm^2/s? **85 °C**
Hint: Go to the viscosity-temperature chart in chapter 10. and follow the line for '46'
8. What are the two basic types of screw compressors? **Oil-flooded and oil-free**
9. What is the typical oil viscosity grade for oil-flooded screw compressors? **ISO VG 46**
10. What do coalescer filters do? **Separate the remaining small droplets of oil from the air (after the large droplets were separated in the reclaimer)**
11. What are different oil suppliers striving to achieve?
(a) **outstanding resistance to oxidation;** *(b)* **high FZG rating;** *(c)* **low tendency to form carbonaceous deposits on valves;** *(d)* **the ability to prevent the blockage of coalescer filters**
12. What will happen if you lubricate a high vacuum pump with an ordinary mineral oil?
It won't work because the the oil vapour will fill the vacuum
13. What will happen if you lubricate a compressor that compresses oxygen with a mineral oil or PAO? **It will explode**

Questions 9.4:
1. For which refrigerants are the following lubricants recommended?
(a) naphthenic oils **Freons, ammonia**
(b) alkyl benzene **Freons, ammonia**
(c) polyol ester **HFC (R-134a) and 'drop-in' mixtures**
(d) PAG **Hydrocarbons, ammonia and CO_2 in some equipment, HFC**
(e) PAO **CFC, carbon dioxide, ammonia (pure PAO only)**

Question 10.0:
1. Which two different types of anti-wear additives are used in hydraulic fluids?
Zinc (ZDDP) and non-zinc which can be ashless

CHALLENGE Hint No. 2
So what is wrong? What Vic is doing obviously does not work and the lubricants are to blame. What correct lubricants should he use and why? Make a table listing all the problems (1st column). With what does Vic lubricate everything? What do we know about those lubricants? Put the lubricants into a 2nd column in the table next to the problems. Continue with the table (3 or 4 more columns), e.g. what is Vic's outcome when he is using his current lubricants and what's the reason for the bad outcome. Consider VISCOSITY - BASE OILS – PERFORMANCE! Then check the Solution (the end of answers) or go to Hint No. 3 (the next page).

REVISION 3:
1. Is EHL relevant to worm gears; why? **No, there is no rolling (that would extremely pressurize the oil), only sliding**
2. Which gear oils have more EP – automotive or industrial and which type of gears requires the highest EP content? **Automotive (GL-5 6%, GL-4 3%, industrial 2% of the same EP package in rough figures), hypoid gears require GL-5 unless lightly loaded**
3. What might be the reasons for the instruction: "Never use EP oils in industrial gearboxes which have an internal backstop"? **It's not clear. The first guess would be that there are some bronze parts that would get damaged. That does not seem to be the case. The correct answer probably is that good EP oils contain some lubricity for friction reduction (thus power saving) which causes the backstop to slip. See:**
http://www.machinerylubrication.com/Read/707/enclosed-gear-drives
http://www.machinerylubrication.com/Read/2020/mixing-lubricants-hazards
4. What are the two common viscosity grades for industrial gearboxes and at what operating temperatures do these grades reach the optimum viscosity in a gearbox described in the text?
ISO VG 220 gets down to 40 mm^2/s at 75 °C and VG 320 at 82 °C
5. What alternatives for lubricating open gears do you know?
Black lube containing bitumen (asphalt) with or without diluent; grease with an extremely heavy oil; and heavy synthetic that is circulated (thus the gears need to be enclosed – are they still "open gears"?)
6. In which aspect(s) are the open gear lubricants unusual?
Base oil: if bitumen or synthetic, viscosity always extremely high (similar to plain bearings in sugar mills)
7. Describe a multi-purpose grease considering all 5 main aspects and explain the significance of each **Base oil mineral (usually nothing better is needed, partially naphthenic which is needed during the production of the grease);**
ISO VG 150 to 200 mm^2/s at 40 °C (for slow to moderate speeds, high loads);
EP for high loads; lithium soap which has no bad properties; NLGI 2 = soft for easy application
8. Describe paper machine oils **Circulating oils with added anti-wear (ZDDP), they have a higher viscosity either ISO VG 220 or 320 and must have good demulsibility and air release; synthetic versions used in Scandinavia**
9. What oils are needed for plain bearings, what is the best quality oil of this type, what is this oil's usual viscosity grade and at what operating temperature does this oil reach the optimum viscosity? **R&O oils, turbine oils are top quality – they are ISO VG 46 so they reach 30 mm^2/s at 50 °C**
10. Give three or four typical oil viscosities for various compressors and their parts
ISO VG 46 for rotary screw air compressors; ISO VG 68 for small reciprocating air compressors and most refrigeration compressors; ISO VG 100 to 150 for cylinders of reciprocating air compressors
11. What is alkyl benzene, where is it used and with what is it compatible and miscible?
Synthetic hydrocarbon that has a low pour point; used in refrigeration compressors with Freons and ammonia; it is compatible with all commonly used sealing materials and miscible with mineral oils
12. What must be done because polyol ester is hygroscopic (readily absorbs moisture)?
After opening the container, close it tightly and use the lubricant within a few days
13. Who is the most important hydraulic pump manufacturer – considering its specification which effectively determines if a hydraulic fluid is 'premium quality'?
Parker Hannifin (Denison)

14. What are the highest and lowest viscosity of hydraulic fluids and why?
In rounded figures: 1000 cSt to be able to suck it in to the pump and 10 cSt to lubricate the pump and prevent excessive leakage
15. What is the main advantage of using high VI hydraulic fluids? **Power saving**
16. Is it a good idea (Yes/No) to use synthetics base stocks in the following applications? If so, exactly in what applications and what synthetics? Can you save energy?
- *Automotive engines* **No, unless you must or costs are not a consideration. But this might change in future when lighter and lighter oils will be used to save fuel and those oils will have to be synthetic to meet the specifications**
- *Two stroke engines* **Only if you need to meet certain specifications or want to have a biodegradable lubricant**
- *Automotive gears* **No, not normally, only in extreme conditions**
- *Automotive transmissions* **There is a clear shift to synthetics in these applications**
- *Brake fluids for cars* **Yes, they are synthetic**
- *Industrial gears, excluding worm gears* **No, only at high temperatures**
- *Worm gears* **Yes, definitely, PAG! Well proven energy savings.**
- *Open gears and big enclosed gears* **Yes, but not too common as yet**
- *Grease applications* **No, only in special applications**
- *Bearings, excluding turbines and paper machines* **No (perhaps not yet)**
- *Steam turbines* **No, except two things: (1) there is a hydraulic system to control the turbine, in some designs, it uses the same oil from the same tank; it would be good, in some cases, to have a fire-resistant fluid in hydraulics, so the idea is to use it in the whole turbine. (2) PAG is promoted in this application.**
- *Paper machine oils* **Exceptions (Scandinavia)**
- *Air compressors* **Yes, except where the oil lubricates only bearings and gears**
- *Refrigeration compressors* **Yes**
- *Hydraulics* **No, only in special applications (or perhaps not yet)**
- *Machine tools* **No**
- *Transformers* **No**
- *Metal cutting and grinding* **Yes, in “High-Water Base Fluid” for grinding**

CHALLENGE Hint No. 3
Vic uses only one oil and one grease in all applications. The oil is an old specification SAE 20W-50, 135 cSt at 40 °C (section 1.7). The grease has a very heavy base oil, perhaps 1000 cSt at 40 °C (section 7.7). **Did you list all the problems and lubricants?** Grease-lubricated bearings on electric motors fail and need replacing: Grease Lathe: surfaces of the cut pieces are not smooth: 20W-50 (2 reasons) Lathe: parts do not move smoothly: 20W-50 Lathe: had to replace some worn gears: 20W-50 Lathe: noise and smoke when cutting: 20W-50 Hydraulic press too slow: 20W-50 Hydraulic press does not want to start: Grease Hydraulic press: bearings get hot: Grease Piston compressor: has to clean the valves (explosion): 20W-50 Piston compressor: air pressure low: 20W-50 (at a reduced feed) Old car's differential loud: 20W-50 and grease Old car: must flush the engine: 20W-50 Old car: must add a special additive: 20W-50 Worm gearbox gears: 20W-50 Wind pump sluggish: 20W-507 Why do Vic's oil and grease cause problems in those applications? Which correct lubricants will eliminate the problems? Try to complete your table and compare it with the Solution on the next page.

CHALLENGE SOLUTION					
Problem	**Lube**	**Outcome**	**Reason**	**Correct lube**	**Note**
Bearings fail	Grease	Lubrication failure	Wrong grease	Bearing grease	80-100 cSt at 40 °C, no EP
Lathe: bad surfaces	20W-50	Jerky feed and bad cutting	Wrong types of oil	Machine tool oil & cutting fluid	See below
Lathe: jerky	20W-50	Stick-slip	Wrong oil	Machine tool oil	ISO VG 68
Lathe: gears	20W-50	Wear	Wrong oil	Machine tool oil	ISO VG 68
Lathe: cut	20W-50	Noise and smoke	Wrong oil	Cutting fluid	Depends on the metal cut
Press: slow	20W-50	Pump cannot cope	Oil too heavy	Hydraulic fluid	ISO VG 46
Press: slow start	Grease	Motor cannot cope	Wrong grease	Bearing grease	80-100 cSt at 40 °C, no EP
Press: hot bearings	Grease	Too much heat generation	Wrong grease	Bearing grease	80-100 cSt at 40 °C, no EP
Compressor: valves	20W-50	Carbon deposits	Wrong type of oil	Compressor oil	Diester is best
Compressor: pressure	20W-50	Worn rings	Oil starvation	Compressor oil	At the correct feed rate
Car: differential	20W-50 + grease	Wear	Too light, not enough EP	Gear oil for hypoid gears	SAE 90 API GL-5
Car: engine needs flush	20W-50	Contaminants left in engine	Level of performance	Good engine oil, 20W-50 is OK	Perhaps API SL
Car: needs additive	20W-50	Oil not good enough	Level of performance	Good engine oil, 20W-50 is OK	Perhaps API SL
Worm gear	20W-50	Wear of the bronze wheel	Wrong oil	PAG	Or Cylinder oil (lubricity)
Wind pump	20W-50	Slow at cold weather	Oil too heavy	Hydraulic fluid	Has the right viscosity

Comments:

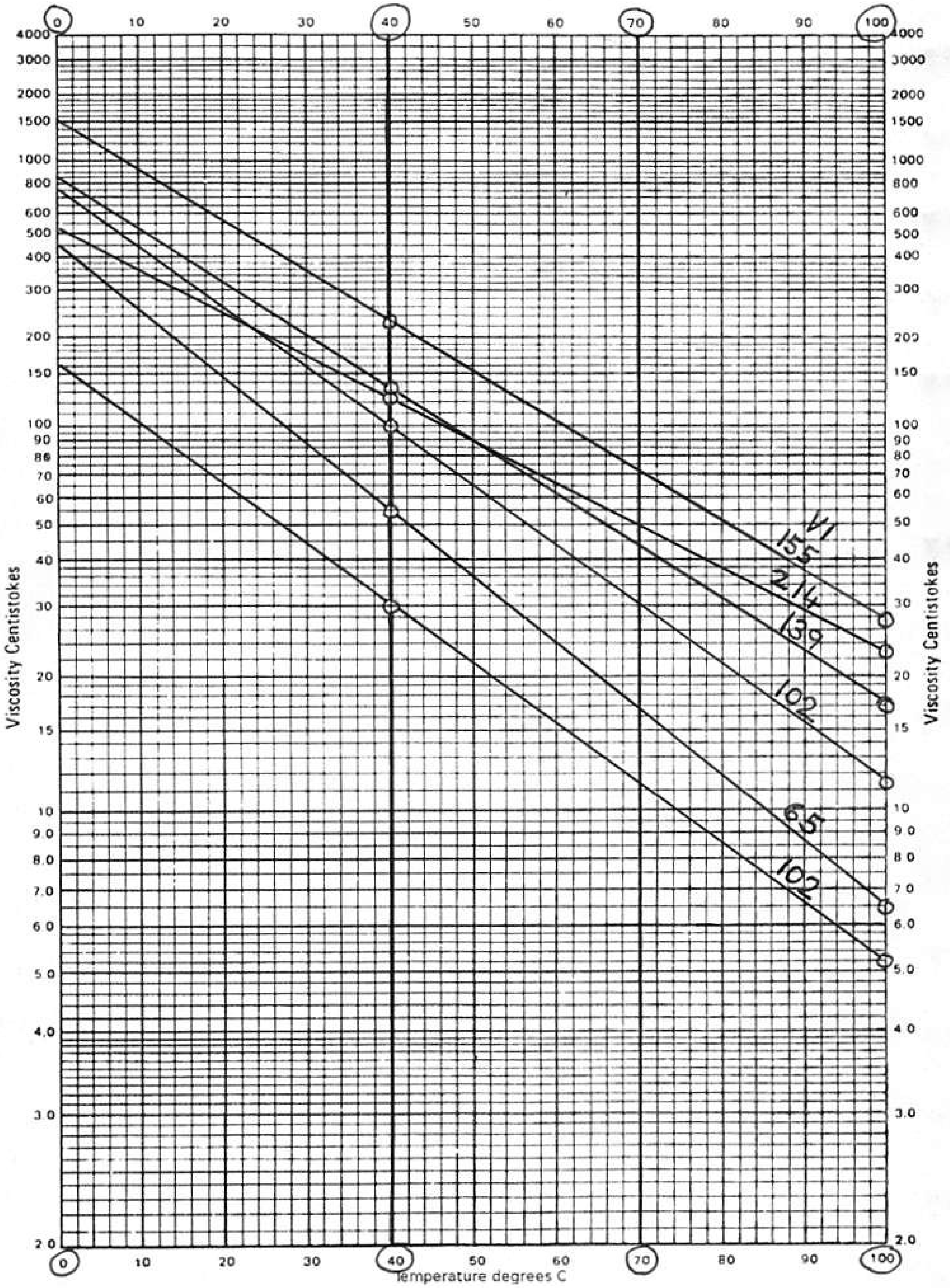
Some problems overlap:

- grease is in bearings of all electric motors, Vic has many of them including one driving the hydraulic pump of the press;
- the bad surfaces on the piece cut on the lathe are probably due to the stick-slip motion of the lathe parts <u>and</u> to using the engine oil as a cutting fluid (which also causes noise and smoke);
- a compressor oil will allow Vic to inspect valves less often and to stop the wear of piston rings – after he changed the rings;
- a better engine oil should solve both car engine problems.

The choice of ISO VG 46 hydraulic fluid would be alright in moderate climate.

It is good to rationalize lubricants (use as few different ones as possible – thus the use of a hydraulic oil in the wind pump) but the applications in our story need correct lubricants.

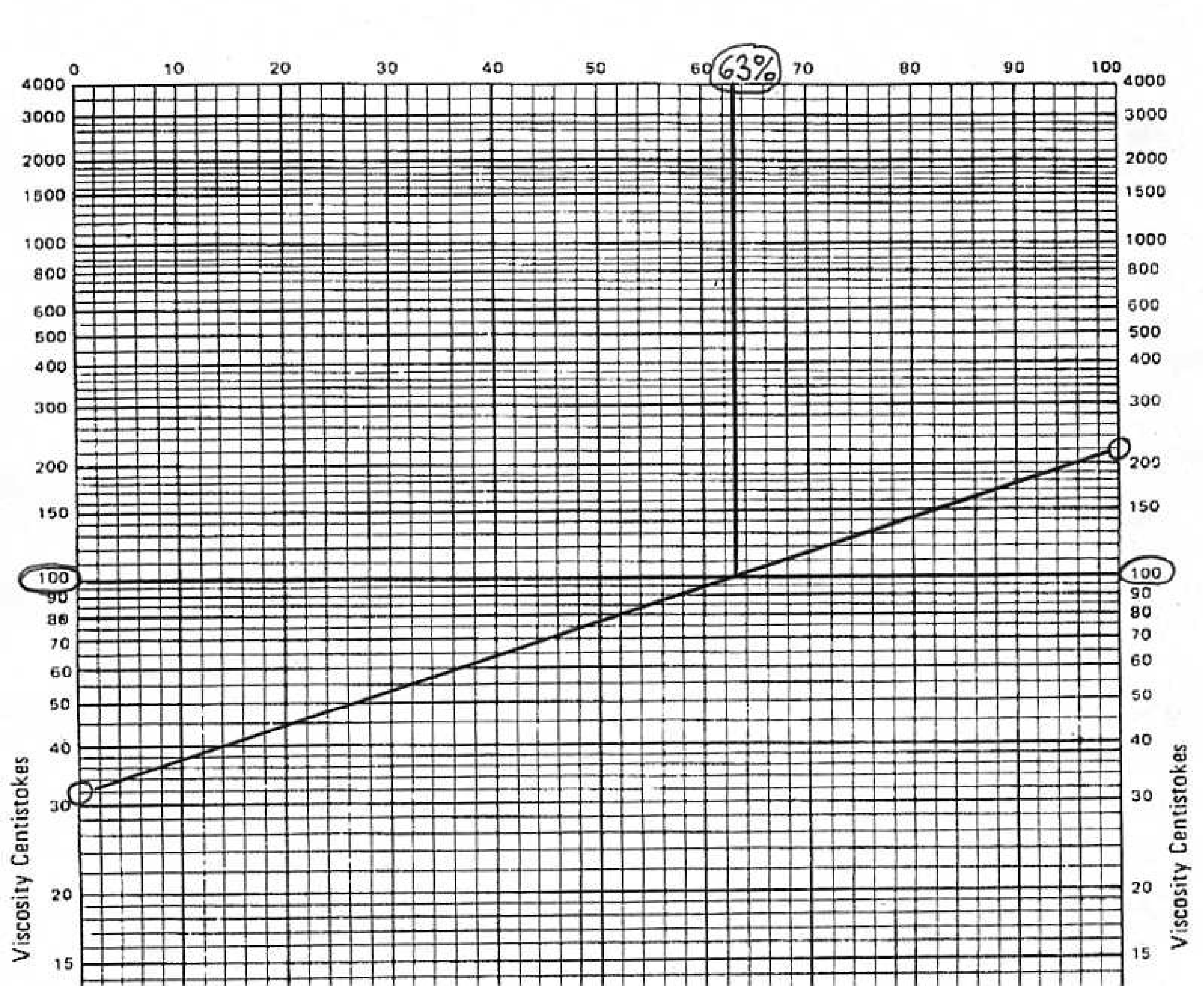
CHARTS



Viscosity Centistokes
Temperature degrees C
VI
155
214
139
102
65
102

Completed viscosity-temperature chartThe chart in 1.7 EXERCISE is dual purpose because it can be used for blending. For example, you have two bearing ('circulating') oils in store: ISO VG 32 and ISO VG 220 but you need ISO VG 100, which you don't have in store. You can mix your two oils to get ISO VG 100.

Steps: 1) Mark a point below '0' at 32 cSt and another point below '100' at 220 cSt. 2) Connect the two points with a straight line. 3) Draw a horizontal line at 100 cSt and where the 100 cSt line crosses your 32-220 line, it shows the required percentages of the two oils. 4) Read the required percentage of the ISO VG 220 oil in the blend at the top horizontal scale (or the bottom scale normally used for temperatures), the result is about 63%. 5) The percentage of the ISO VG 32 oil in the blend would then be 37%. You can see it here:



Today, the calculation is more often done by using online calculators.

To get the right viscosity, two viscosity grades of base stocks are usually mixed. But it's not a good idea to mix oils that have very different viscosities (such as VG 32 and 220) because you get a mixture of very different molecules that might not support the load as effectively as a 'straight cut' (one base oil) or close base oils would do. Some authors would say that such a mixture has an inferior 'film strength'.

We do not like and do not use the term 'film strength' because it is not standardized and there is no good test method to measure it. Different authors use it for different purposes, some confuse it with adequate viscosity for the given load, speed and temperature. We would use the term only to describe situations where the lubricant contains foreign matter, such as water droplets or air bubbles – such lubricating films are of course inferior or even catastrophic.

Viscosity-temperature chart with added viscosity grades