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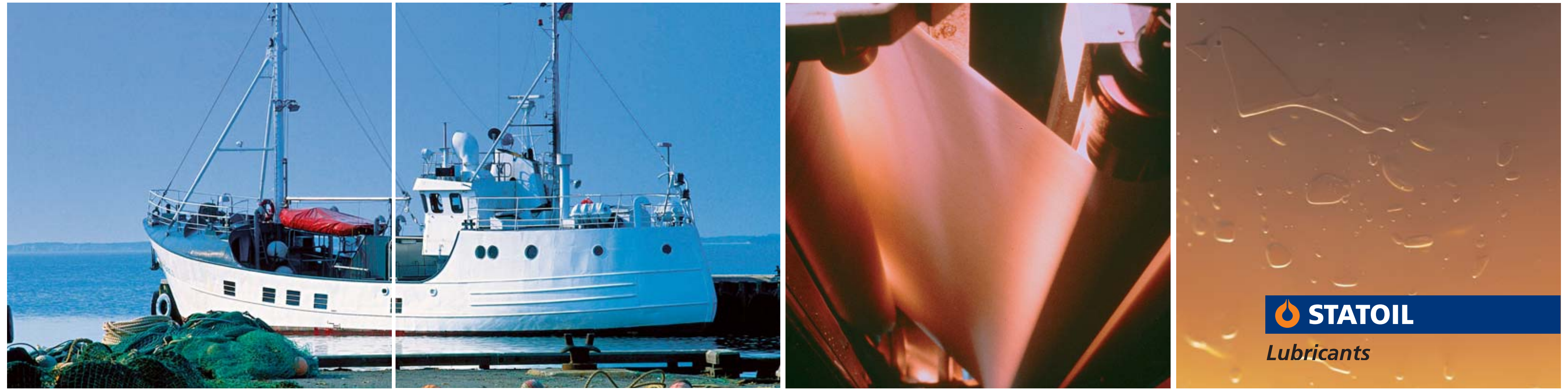
# Hydraulic Fluids

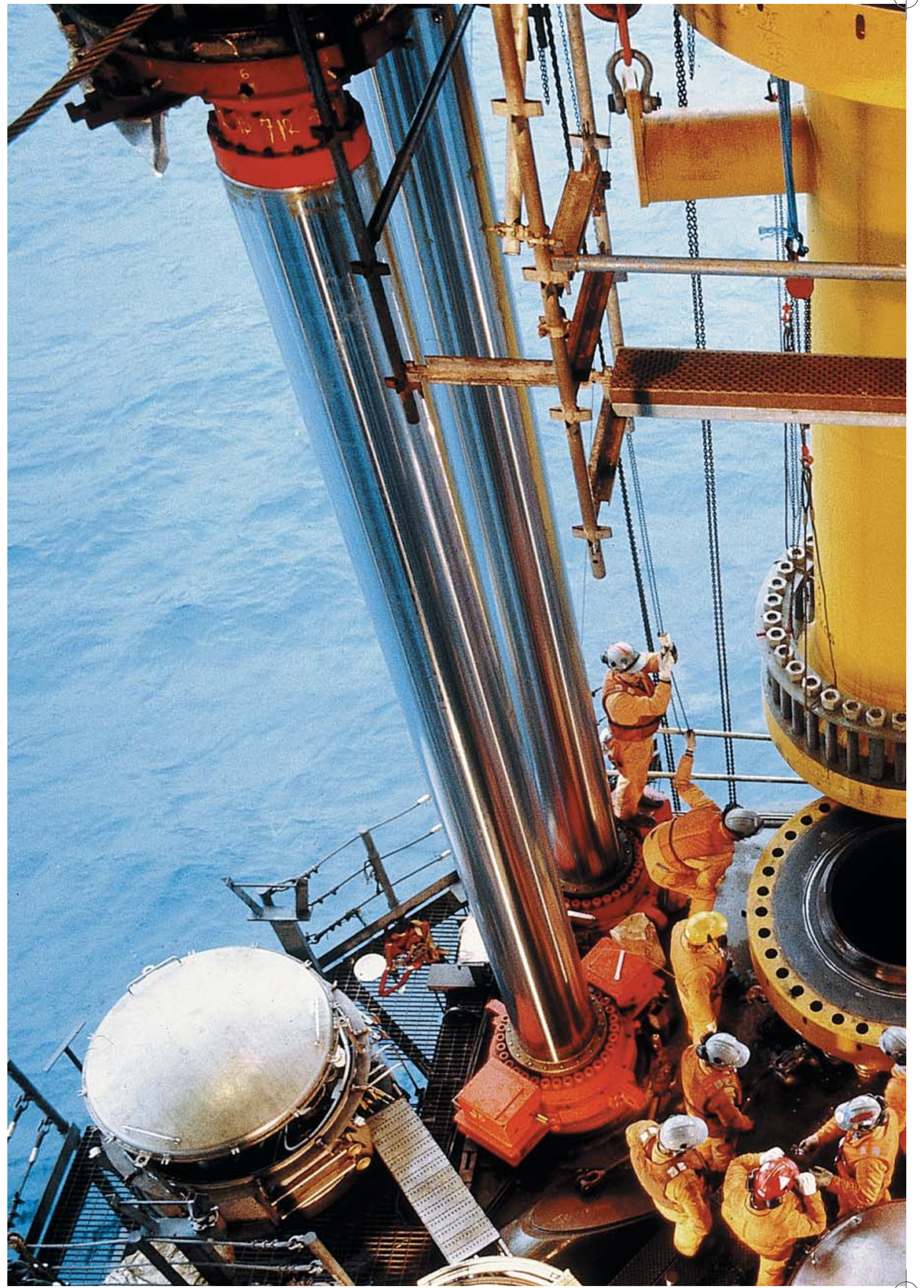


# Contents

Hydraulics is a technique for transferring energy using a fluid as the energy carrier. The fluids that are used for this purpose are known as hydraulic media.
The hydraulic fluid is in contact with all the components in a hydraulic system. It transfers power, lubricates, prevents corrosion and wear, and moreover acts as a heat transfer medium. At the same time, the hydraulic oil transports solid contaminants to the system's filters.







# The hydraulic system

## *Trends*

In addition to the hydraulic fluid, a typical hydraulic system contains the following main components:

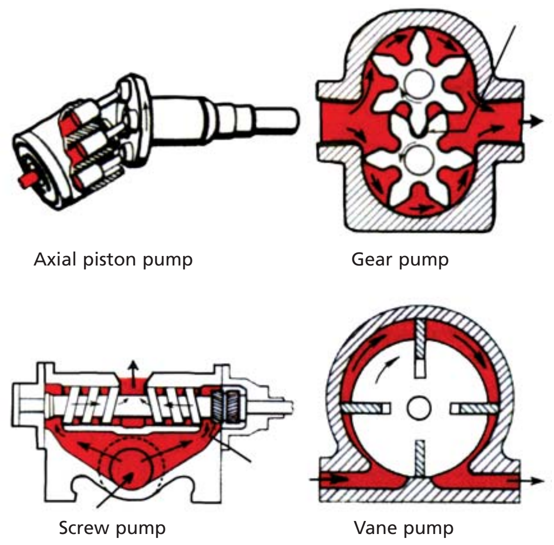
- **Pump:** Ensures that the necessary working pressure is achieved.
- **Pipelines and hoses:** Conduct the flow of fluid between the components.
- **Valves:** Control the direction, pressure and volume of the fluid.
- **Cylinders:** (Linear or rotary engine) convert the fluid pressure (the hydraulic energy) into mechanical energy.
- **Oil tank:** Provides the oil with the potential to separate any content of water, air or other contaminants.

The most important component in the hydraulic system is the pump, and it is typically this that is the controlling factor when choosing which type of hydraulic fluid is to be used.
Depending on the hydraulic system, different pumps are suitable. The four most common types of hydraulic pump are:

- **Gear pumps**
- **Vane pumps**
- **Screw pumps**
- **Piston pumps**

These main types can be varied in many ways to meet specific requirements.

*Fig.: Hydraulic pump types*




**Trends**
Modern hydraulic systems contain extremely sensitive components that are produced with a very high level of precision. The trend within mobile hydraulics is for considerable emphasis to be placed on fuel economy.
Demands for lighter machines with smaller hydraulics systems are leading to the cylinders becoming smaller, higher pressure and temperature, and a lower oil volume in the system. This places additional stringent demands on the hydraulic oil.
The demands placed on the hydraulic fluid are similarly high within industrial hydraulics, with the focus on energy economy and very high cleanliness requirements in the systems.

# Types of hydraulic oil

## *Mineral oil-based hydraulic oils*

The most common hydraulic oils used at present are based on mineral oils or biodegradable oils.

**Mineral hydraulic oils**
Mineral hydraulic oils are classified in accordance with ISO 6743/4 and DIN 51524.

| Description | ISO | DIN |
|---|---|---|
| Mineral oil without additives | HH | H |
| Type HH + oxidation and corrosion-inhibiting | HL | HL |
| Type HL + wear-inhibiting | HM | HLP |
| Type HL-P + detergent (“self-cleaning”) | – | HLPD |
| Type HM + viscosity-improving | HV, HR | HVLP |
| Type HM + anti-stick-slip | HG | – |

Table 1

**HH oils**
Basic circulation oils, usually without additives. The oils have a relatively short lifetime as they are not oxidation-stable and are consequently broken down. No longer particularly widespread in Western Europe.
HH in accordance with ISO 6743/4.

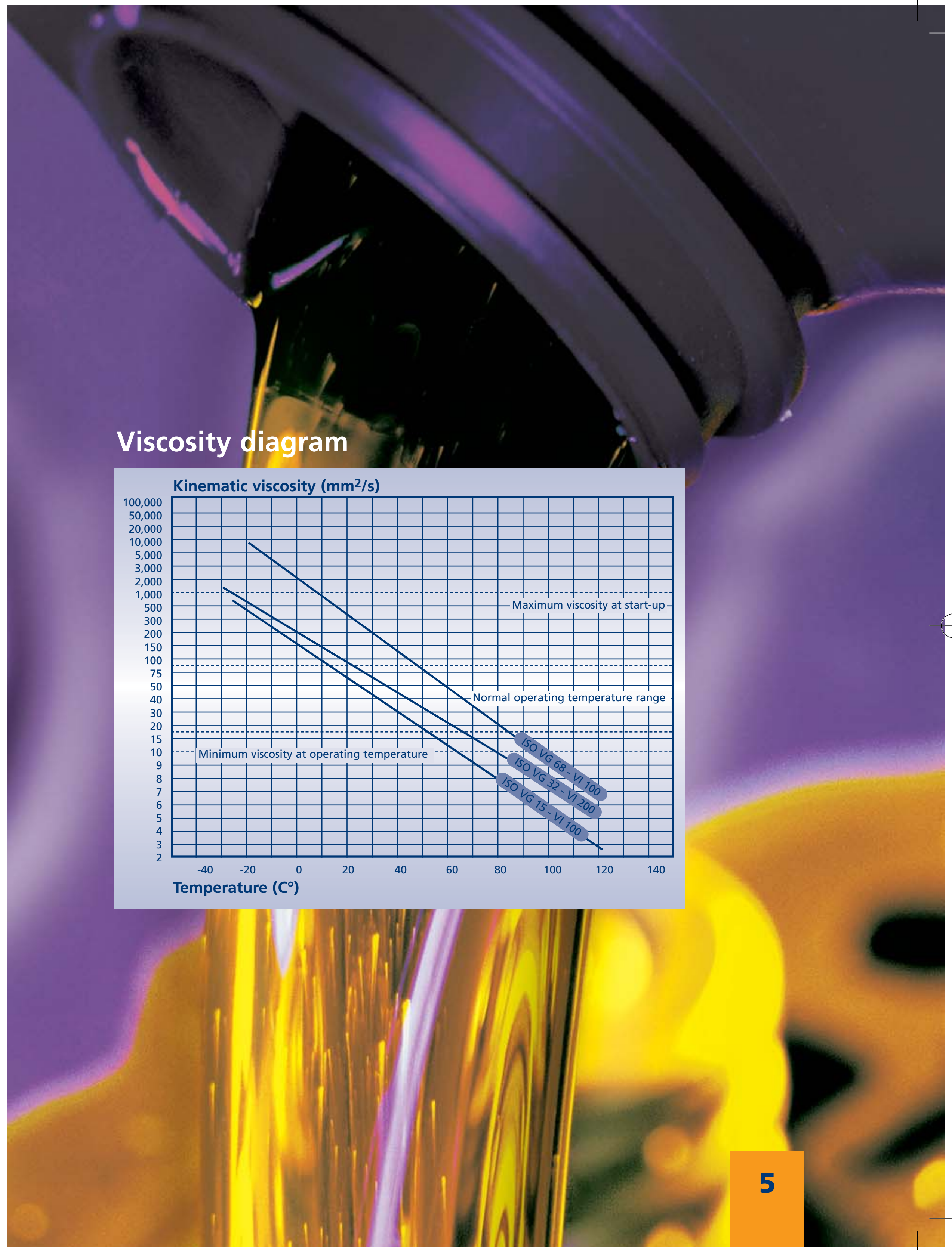
**HL oils**
Hydraulic oils with additives against oxidation and corrosion. On the basis of improved oxidation stability, the oils will have a relatively longer lifetime.
They are used in hydraulic systems that have no specific requirements as regards the oil’s anti-wear properties and for systems that operate under low pressure.
HL in accordance with DIN 51524, part 1.
HL in accordance with ISO 6743/4.

**HLP oils**
Hydraulic oils with additives against oxidation and corrosion, as well as additives that should reduce wear and/or improve the high-pressure properties (EP properties).
This is the most widely used type of hydraulic oil and is a universal hydraulic oil for a large group of applications that require a long lifetime and good protection against corrosion and wear.
HLP in accordance with DIN 51524, part 2.
HM in accordance with ISO 6743/4.

**HLPD oils**
Hydraulic oils which, in addition to additives, as in the HLP oils, include a cleaning additive (detergent).

**HVLP oils**
Hydraulic oils which, in addition to additives against oxidation, corrosion and wear, also contain additives that improve viscosity. They have a viscosity index (VI) of > 140 and hence have good viscosity/temperature properties.
By comparison, the HLP oils have a viscosity index of around 100.
In addition, the HVLP oils contain a pour point improver.
The high viscosity index is achieved through the addition of additives and/or by using a base oil with a naturally high VI.
A naturally high VI in the base oil is preferable, because this avoids shear-losses. If a viscosity-improving additive is used, it is important that it has a high mechanical stability so that there is no shear-loss in the molecules, which would lead to a viscosity reduction. Shear stability is a measure of an oil’s ability to withstand viscosity reductions due to the breaking down of the VI improver.
The HVLP oils are used within a wide temperature range.
Examples include mobile hydraulics and critical systems such as machine tools.
HVLP in accordance with DIN 51524, part 3.
HV in accordance with ISO 6743/4.

**HG oils**
These have additives to improve their stick-slip and anti-stick-slip properties. These additives prevent jerky movements, which can arise in the event of very low sliding speeds and high loads.
HG oils are used for example in hydraulic elevators and cranes.
HG in accordance with ISO 6743/4.



# Types of hydraulic oil

## *Environmentally adapted hydraulic oils*

**Environmentally adapted oils**
The environmentally adapted oils are characterised by the fact that the base oil and the additives that are included in the lubricant have been selected on the basis of them having the least possible negative impact on the environment in the event of leakage.
Neither should the oil have any classification obligation with regard to health risks or content of allergenic substances. (Total max. 1%)
When assessing an oil's environmental properties, two factors that are considered are the oil's biodegradability and its toxicity to organisms in the environment (on land and in water). Another factor is whether the oil consists of renewable raw materials.
Biodegradation is a process whereby micro-organisms, with the aid of oxygen, break down organic material and use the products to provide themselves with nutrition. In the event of complete biodegradation of hydrocarbon compounds, which in some cases requires considerable access to oxidation, the end products are carbon dioxide and water.
The requirement in accordance with the relevant standards is that the biodegradability should be:
$ 60% after 28 days in accordance with OECD 301 B, C, D or F
$ 80% after 21 days in accordance with CEC L-33-A-93

The first generation of biodegradable oils, based on rape seed oil, which came onto the market in 1980, were not of a particularly good quality. This led to the following problems:

- Oxidation, sludge formation and hydrolysis at temperatures > 70°C
- Jelly/ice formation and flow problems at temperatures <0 to –15°C
- Leaking sealing materials
- Unstable during storage

This led to biodegradable oils gaining a poor reputation, while the current generation of biodegradable hydraulic oils typically have better technical properties than traditional mineral oils.
There are several systems for classifying biodegradable oils, including VDMA 24568. (Table 2)
VDMA 24568 divides the oils into groups, dependent on which base oil it comprises.

| Description | VDMA 24568 |
|---|---|
| Polyalkylene glycols, soluble in water | HEPG |
| Triglycerides (vegetable oils), non-soluble in water | HETG |
| Synthetic in water | HEES |
| Polyalphaolefins (PAO) and/or other similar hydrocarbons, non-soluble in water | HEPR |

Table 2

Another standard, which includes environmental criteria, is Swedish Standard SS 15 54 34.

**"Hydraulic Fluids – Requirements and Test Methods"**
This does not divide the oils into groups according to base oil type, but sets technical demands and environmental requirements independent of which base oil the oils comprise.

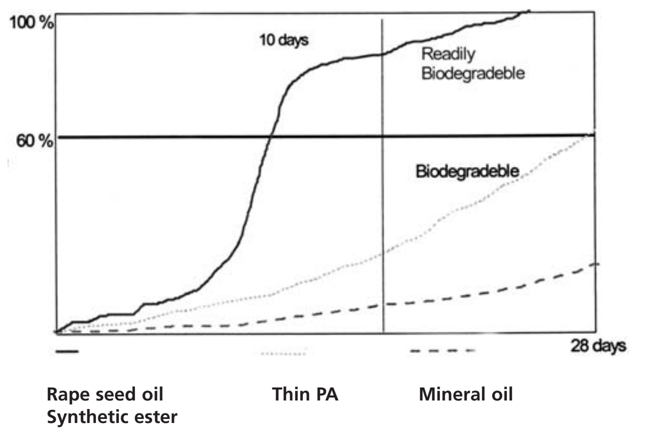
**Hydraulic oils based on synthetic esters**
Synthetic esters are a group of substances whose structure demonstrates considerable variation. Esters are produced during a chemical reaction between alcohol and acid. Alcohols and acids from a broad spectrum of raw materials are combined to achieve the desired properties. For example, properties such as thermal and hydrolytic stability, low temperature properties and compatibility with sealing materials.
Hydraulic oils based on synthetic esters now deliver very good properties with regard to shear stability (based on a natural, high VI), oxidation and hydrolytic stability.

**Hydraulic oil based on vegetable oil**
A vegetable oil is produced from raw materials from the vegetable kingdom, such as rape, sunflower or soya oil. The oil is pressed out of the seeds and refined to the desired grade. Vegetable oil is a natural ester with good lubricating properties, it is biodegradable and has extremely good environmental properties.

**Hydraulic oil based on polyalphaolefins (PAO)**
Polyalphaolefins with a low viscosity are biodegradable, which is why biodegradable hydraulic oils based on PAO can also be found.
This type of oil offers very good oxidation stability and very good high and low temperature properties.
These oils normally contain a large proportion of VI-improving additives. It is therefore important to remember that the shear stability in these products can vary.

**White oil-based hydraulic oils**
White oils consist of highly refined mineral oils that are colourless, odourless and possess a high level of cleanliness. Hydraulic oils based on white oil give a better working environment and are primarily used within industrial hydraulics.
In particular, oils of this type are used within the food industry, which places extremely stringent cleanliness demands on the oil. The cleanliness demands are regulated by NSF (formerly USDA and FDA).

**Biodegradability in accordance with OECD 301**



# Types of hydraulic oil

## *Fire-resistant hydraulic fluids*

**Fire-resistant hydraulic fluids**

Fire-resistant hydraulic fluids have been developed for use within mining, steelworks, pressure die casting and aeronautical applications. These fluids have a significantly higher combustion temperature than mineral oils and are therefore more fire resistant.

This increases safety levels for operators, minimises the risk of fire and damage to equipment, as well as minimising the risk of interruptions and production stoppages.

The fire-resistant hydraulic fluids are classified in accordance with DIN 51502 and ISO 67434

| Description | ISO | DIN |
|---|---|---|
| Oil-in-water emulsions, mineral oil or synthetic ester | HFA E | HS-A |
| Water-based solutions of chemicals. Free of mineral oil. Water content > 80% | HFA S | – |
| Water-in-oil emulsions. Mineral oil content approx. 60% | HFB | HS-B |
| Water-polymer solutions. Water content > 35% | HFC | HS-C |
| Anhydrous synthetic fluids consisting of phosphates. Non-soluble in water. | HFD R | HS-D |
| Anhydrous synthetic fluids with a different origin, for example esters from carbolic acids | HFD U | HS-D |

Table 3

**HFA E fluids**

Oil-in-water emulsions that contain a maximum of 20% oil. The viscosity is almost the same as water (0.8 $mm^2/s$). These fluids have poor anti-wear properties, and hydraulic systems normally have to be converted in order to use fluids of this type. Gear pumps and axial piston pumps are better suited than vane pumps in such units.

The water quality is also important, as hard water can result in deposits of calcium compounds, while soft water can result in foaming. The fluids also often have biocides added to them to counteract biological growth. Biological growth is always a potential danger in conjunction with hydrous media at moderate operating temperatures.

HFA E fluids are now not used to any great extent.

HS-A in accordance with DIN 51502.

HFA E in accordance with ISO 6743/4.

**HFB fluids**

Water-in-oil emulsions with a content of mineral oil (flammable) of approx. 60%. These fluids are currently primarily used in the mining industry in the UK and other countries influenced by the UK. Due to the high mineral oil content, these are not approved in a spray-combustion test, which is required in Germany and a number of other countries.

HS-B in accordance with DIN 51502.

HFB in accordance with ISO 6743/4.

**HFC fluids**

HFC fluids are normally based on a mixture of demineralised water with polyglycols as thickeners and with the addition of wear-inhibiting and foam-inhibiting additives, as well as corrosion inhibitors.

The water content must be at least 35% to ensure satisfactory fire-inhibiting properties. This level should be achieved in order to avoid changes in viscosity.

Systems for HFC fluids must not contain components made of magnesium, cadmium or zinc.

HS-C in accordance with DIN 51502.

HFC in accordance with ISO 6743/4.

**HFD fluids**

The majority of HFD fluids currently used in industry are phosphoric acid esters and organic complex esters.

Fluids of this type entail several restrictions with regard to the system's design and the choice of materials. When converting to such a fluid, it is always necessary to contact both the component and the system supplier to make sure that the fluid is compatible with the relevant metals, sealing materials and any paint types or tank coatings.

HS-D in accordance with DIN 51502.

HFD in accordance with ISO 6743/4.

# Types of hydraulic oil

## *Engine oil in hydraulic systems*


**Engine oil in hydraulic systems**
In mobile installations, particularly within agricultural machinery and construction machinery, it is both possible and practical to use the same oil for both engine and hydraulic system. It is important to know that hydraulic and engine oils have different structures. For example, engine oils contain detergent (cleaning) and emulsifying (hold particles in suspension) additives, also known as “self-cleaning” additives. Engine oils are comprised in such a way that they should bind a relatively large amount of water, while hydraulic oils are comprised so that they separate out water.
The water can create an emulsion with the detergent and emulsifying additives (“self-cleaning”), and this can lead to filtration problems. It is therefore important that the working temperature in the mobile installation is occasionally higher than 65°C so that as much of the water as possible evaporates.
Hydraulic oils also have a better ability to separate air than engine oils.

**ATF oils in hydraulic systems**
ATF oils (Automatic Transmission Fluids), which are used in automatic gears, are primarily comprised with a view to having the correct friction characteristics. At the same time, these products have a high viscosity index and good properties regarding anti-wear, shear stability, oxidation stability, foaming and air separation. This means that oils of this type are also used as hydraulic oils, for example in ships as well as in construction machinery and agricultural equipment.
Most producers of hydraulic equipment stipulate certain requirements as regards the hydraulic media that are to be used. Occasionally this is limited to viscosity recommendations. However, the constant development of new technology within hydraulics is continually placing more stringent demands on the hydraulic oil. These demands are expressed in specifications, and can include requirements for oxidation stability, filterability and wear-inhibiting properties.
The most important specifications include:



# Demands placed on the hydraulic oil

## *Specifications*

**DIN 51524, part 2**
This places demands regarding the wear-inhibiting properties, for example. (The demands that detailed under the specifications are only the most critical; each specification also contains a number of other requirements.)

**Vickers M-2952-S and Vickers I-286-S**
Describe hydraulic oils in mobile equipment. Viscosity limits and approved performance in the pump tests Vickers V 104C and the challenging Vickers 35VQ25.

**Denison HF-0**
Prescribe high thermal stability in the Cincinnati Milacron test (168 hours at 135°C) and hydrolytic stability in relation to ASTM D 2619. Also stringent demands regarding oxidation stability, anti-wear and filtration capacity.

**Swedish Standard SS 15 54 34**
For example places demands regarding flow properties at low temperatures under Nordic climatic conditions.

# Demands placed on the hydraulic oil

## *Important properties*

**Viscosity**
Viscosity is a measure of a fluid's internal friction or flow resistance. We often say that the viscosity indicates a fluid's thickness. The higher the value, the thicker or more viscous the fluid is.
Viscosity is specified as kinematic or dynamic. Kinematic viscosity corresponds to the oil's dynamic viscosity divided by density. For hydraulic fluids (and other industrial oils), it is most common to specify the kinematic viscosity in centistokes or $mm^2/s$, at 40°C.
The oils are classified with regard to viscosity in accordance with the ISO 3448 standard. This standard contains 18 main groups with the designation ISO VG (viscosity degree).

| Viscosity class in accordance with ISO 3448 | Kinematic viscosity $mm^2/s$ at 40°C | |
|---|---|---|
| ISO VG 2 | Min. | Max. |
| ISO VG 3 | 1.98 | 2.42 |
| ISO VG 6 | 2.88 | 3.52 |
| ISO VG 7 | 4.14 | 6.06 |
| ISO VG 10 | 6.12 | 7.48 |
| ISO VG 15 | 9.0 | 11.0 |
| ISO VG 22 | 13.5 | 16.5 |
| ISO VG 32 | 19.8 | 24.2 |
| ISO VG 46 | 28.8 | 35.2 |
| ISO VG 68 | 41.4 | 50.6 |
| ISO VG 100 | 61.2 | 74.8 |
| ISO VG 150 | 90 | 110 |
| ISO VG 220 | 135 | 165 |
| ISO VG 320 | 198 | 242 |
| ISO VG 460 | 288 | 352 |
| ISO VG 680 | 414 | 506 |
| ISO VG 1000 | 612 | 748 |
| ISO VG 1500 | 900 | 1100 |
| | 1350 | 1650 |

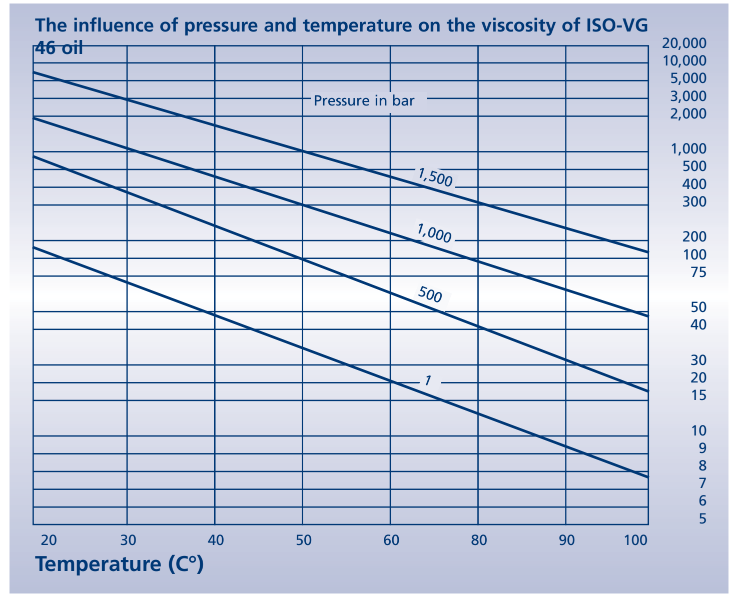
Table 4

The viscosity is influenced to a large extent by the temperature, as the viscosity increases as the temperature drops and reduces as the temperature rises.
The change in the oils' viscosity in relation to temperature is indicated with the oil's viscosity index, V.I.
V.I. is an index measure that relates the kinematic viscosity at 100°C to the viscosity at 40°C.
The higher the V.I. an oil has, the less the viscosity changes as the temperature changes.
The viscosity's temperature dependence is determined by the oil's chemical structure and any content of viscosity index-improving additives.
Mineral oil-based hydraulic oils normally have a V.I. of approx. 100. Some synthetic and vegetable hydraulic oils have a V.I. of over 200.
Mineral oil-based hydraulic oil, which will primarily be used in mobile installations or within a large temperature range, have a V.I.-improving additive. The V.I. for these oils is then normally in the range 150–180. Hydraulic oils with such a high V.I. cover a large viscosity range. In practice, this provides the potential to replace several oil viscosities with a V.I. of approx. 100 and with one hydraulic oil with a V.I. of approx. 160.
By adding additional V.I.-improving additives, oils can be produced with a V.I. of 350–400.
It is important that the polymer that is used is shear stable so that it does not break down after a short period of use, because this lowers the viscosity.
The viscosity is also affected by the pressure, although to a much lesser extent than by the temperature. For example, the pressure in the oil must rise from atmospheric pressure to around 350 bar before the viscosity of a normal hydraulic oil doubles.

(When selecting hydraulic oil with regard to viscosity, see chapter 5: Choice of hydraulic fluid.)

**Cold properties**
When the temperature drops, an oil becomes more viscous. It is therefore important to determine the oil's cold properties. It is normal to state the lowest pour temperature for the oil, i.e. the temperature at which the oil, under certain specified test conditions, cannot flow any more.
By selecting a hydraulic oil that has a pour point of at least 10°C below the lowest anticipated starting temperature, it is probable that the system will function well.
When a mineral oil is cooled down to –30°C, for example, it takes approx. 24 hours for the viscosity to stabilise, while for a vegetable oil this can take up to 5-6 days. In the Swedish standard SS 155434, a requirement for maximum viscosity after 3 days' storage at –20°C and –30°C respectively is specified.

**Compressibility (Hydraulic oil under pressure)**
Compressibility (where the oil's volume is reduced) is dependent on pressure and temperature.
At pressures up to 400 bar and temperatures up to 70°C, compressibility is of little importance to the system. At pressures from 1,000 bar and upwards, changes in the compressibility can be registered. The compressibility is usually of little importance, but when dimensioning filters for example, it can be very important.
If the hydraulic oil is used under very high pressure, the fact that the oil acquires a higher viscosity must be taken into consideration. For example, the oil's viscosity doubles when the pressure increases from 1 bar to 400 bar.



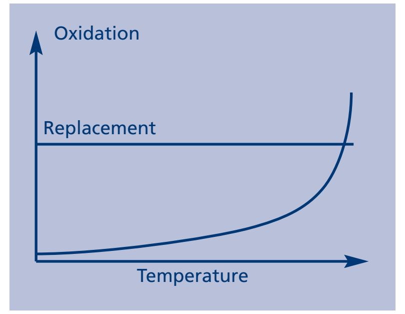

**Wear-inhibiting properties**
In order to improve the oil's ability to counteract grinding wear between heavily loaded contact surfaces, the hydraulic oil is provided with a wear-reducing additive.
Even if the hydraulic manufacturers do their utmost to achieve the best possible operating conditions in the hydraulic system, there are often a series of unfavourable contacts that make hydrodynamic lubrication difficult.
The most common wear-reducing additive used in hydraulic oils is zinc dialkyl dithio phosphate (ZDDP).

# Demands placed on the hydraulic oil

## *Important properties*

Zinc-free wear-reducing additives have been available and have been used on the market for many years. One important factor, which is increasingly the focus of attention, is that the zinc-free wear-reducing additives have less of an impact on the environment than those containing zinc. Zinc is extremely toxic to aquatic organisms.
The authorities in various countries are tightening up the national requirements regarding the use of chemicals that have an impact on the environment, and it is expected that the use of hydraulic oils that contain zinc will be regulated in the future.
Many industrial business, as well as off-shore installations, do not now wish to use hydraulic oils containing zinc. Zinc-free hydraulic oils produce no ash during combustion, and are therefore referred to as ashless.
Zinc-free hydraulic oils can also be used in businesses' "green accounts".
A hydraulic oil's lubricating capacity, anti-wear properties and high-pressure properties can be tested in various ways.
The most common test methods are Vickers' pump tests V 104C, Vickers 35VQ25, FZG gear rig, 4-Ball test, AFNOR E48-603, DIN 51350 and DIN 51354.

**Oxidation stability**
Oxidation stability is an expression of the oil's ageing resistance. When the oil comes into contact with the oxygen in the air, a chemical process begins. The hydrocarbon molecules in the mineral oil react with oxygen and form compounds




such as organic acids, hydroperoxides and alcohols.
The oxidation products can be viscous, sticky deposits or varnish-like, which for example can result in valves becoming stuck.
The oxidation process is primarily affected by the temperature, the access to oxygen (air) and catalytic metals such as copper and iron.
The ideal working temperature for a hydraulic installation is between 60–70°C, and at this temperature a hydraulic oil that contains anti-oxidation additives can have a lifetime of several thousand hours. However, the oxidation speed displays an accelerating course in relation to the temperature, and can be said to double every 8–10°C . Based on this, it can also be said that the oil's lifetime is halved for every 10 degrees that the oil exceeds approximately 65°C.
There are several laboratory tests that can analyse oxidation stability.
The TOST test (DIN 51587) is one of the most common. The oxidation stability is characterised by the increase in the neutralisation value when the oil is exposed to oxygen, water, steel and copper for 1,000 hours at a temperature of 95°C.
The maximum limit for the neutralisation value is 2 mg KOH/g after 1,000 hours.



**Air separation**
Mineral oil-based hydraulic oils normally contain 7-9% by volume of dissolved air at atmospheric pressure. As long as the air is dissolved in the hydraulic oil, it is of secondary importance. However, pressure changes in the system can result in the formation of free air bubbles, and the consequence is noticeable in the form of noise, unreliable operation and possibly damage to pumps and other components. Non-dissolved air is a common cause of cavitation on the suction side of hydraulic pumps.
The reason for the absorption of non-dissolved air might be leaks in the suction line, connections or contamination with another oil grade containing additives that reduce the hydraulic oil's ability to separate air, such as engine oil.
Foam forms on the surface, and this is a consequence of the air separation in the oil. However, a foam-inhibiting additive is added to the oil, which should prevent the build-up of surface foam.
The addition of extra foam-inhibiting additive to a hydraulic system experiencing foam problems can reduce the foam on the surface in the tank, but cannot prevent free air being bound in the oil. In the event that the foam-inhibiting additive is overdosed, the oil's air separation ability will be reduced and operating problems will arise, despite the fact that there is a low level of foam in the tank. If is therefore important to identify the cause of the foam problems and take the necessary action, instead of the short-term solution of adding more foam-inhibiting additive.

**Water separation**
An important property is the hydraulic oil's ability to separate water.
Water contamination can for example result from leakage from the cooler, condensation or through leaking gaskets.
Water in the hydraulic system can cause corrosion, cavitation in pumps, filter problems, an increase in friction and wear, and can also have a negative effect on the durability of the gaskets.
It is important that free water can be drained from the system, and it is a requirement that emulsified water in the hydraulic oil can rapidly be separated.
The oil's demulsification capacity differs between new and used oil. Used oil has a poorer demulsification capacity than new oil. Contamination by another type of oil, such as engine oil, can greatly reduce the hydraulic oil's ability to separate water. Contamination with engine oil can also lead to sludge formation and deposits being formed in valves and filters.

# Demands placed on the hydraulic oil

## *Important properties*

**Rust and corrosion-prevention properties**

Corrosion can occur in the hydraulic system when water is present. Even small amounts of corrosion products can have catastrophic consequences for a hydraulic system.
Hydraulic oils therefore have anti-corrosion additives, which are intended to counteract corrosion. The risk of corrosion attacks is also reduced if you try to prevent water penetration and ensure that the system is drained regularly.

**Hydrolytic stability**

A few types of base oil, such as natural or synthetic esters, as well as certain types of additive, demonstrate a tendency to react with water. During a chemical reaction between a fatty acid and an alcohol, ester and water are produced. This reaction is reversible, in other words if water comes into contact with the ester, it can revert to the original state, i.e. fatty acid and water. The oil will have a lower flash point and acidic constituents will be formed (the acid value increases).
Filterability will be poorer, and there will be an increased risk of filter penetration. The acidic products that are formed during hydrolysis can attack sensitive metals in the hydraulic system.
Esters, which are used in high-quality environmentally adapted hydraulic oils, are selected on the basis of requirements for the best possible hydrolytic stability, but it is still important to ensure that you select an oil with documented, good hydrolytic stability.

**Elastomer compatibility (Sealing materials)**

One important requirement for hydraulic oils is that they must be compatible with sealing materials and hydraulic hoses.
The optimum in order for the hydraulic system to remain sealed is a moderate swelling (2%). Hose and gasket producers should always be contacted if you are in any doubt as to whether the hydraulic oil is suitable for the hydraulic system.
One of the most common materials in hoses (internal) and gaskets is nitrile rubber (NBR). The Swedish standard specifies requirements regarding the oil's effect on this type of material.
Many other materials are used in hydraulic systems, including fluororubber (FPM with the trade name Viton),

**Unsuitable (-) and suitable (+) sealing materials for mineral hydraulic oils**

÷ **Natural rubber Polychloroprene** (Neoprene)
**Isobutylene isopropene**

\+ **Acrylonitrile rubber** (Nitrile rubber)
**Polysulphurised ethylene**
**Fluoroelastomer** (Viton)



# Correct choice of hydraulic oil

## *Optimum viscosity grade*

Polyester urethane (AU) and Polyether urethane (EU).
Materials that are not suitable include Natural rubber, Polychloroprene (Neoprene) and Isobutylene isoprene.
In order to choose the right hydraulic oil, it is advisable to obtain as detailed information about the system as possible.
Factors that should be evaluated are:

- Within what temperature range should the system work?
- What are the upper and lower viscosity limits?
- The manufacturer's recommendations with regard to the most critical components (in particular the hydraulic pumps).
- Any specific requirements regarding lubricating properties in conjunction with any of the components.
- Any limitations for any of the system's construction materials, for example seals.
- Is it a requirement for the oil to be biodegradable?

A hydraulic oil should be able to accomplish all of its particular work duties, ideally with a good safety margin. Although economy is important, it is often not profitable to select the oil that only satisfies the pump producers' minimum requirements.
The choice on each occasion is dependent on what it costs to purchase a slightly better oil and what benefits are achieved in the form of less wear and greater operational reliability.

**Optimum viscosity grade**

The optimum viscosity for a hydraulic system is a compromise between the demands for lubrication capacity and mechanical and volumetric efficiency, see table 5.
This balance can best be determined through practical trials, and will often be nearest the lowest viscosity that is necessary to avoid wear in the pumps.
Different pump types place different demands on the hydraulic oil's viscosity (table 5), and the climatic conditions in the Nordic region can represent a significant challenge in connection with hydraulics for outdoor use.
As a general rule, the viscosity of the oil that is used should be within the viscosity range 10–1500 $mm^2/s$ at start-up of the system, in order for cavitation problems and wear to be avoided.
For optimum efficiency, the viscosity at operating temperature should be between 20 and 50 $mm^2/s$.

| Pump type | | Viscosity $mm^2/s$ | | | Suction capacity mm Hg, (bar) |
|---|---|---|---|---|---|
| | | Min. | Recommended | Max. | |
| Gear | - slide bearings | 25 | 25 | 1000 | 430 (0.57) |
| | - roller bearings | 16 | 20 | 1000 | 430 (0.57) |
| Piston | - servo valves | 8 | 20 | 200 | 25 (0.03) |
| | - port/seat valves | 16 | 25 | 500 | 125 (0.17) |
| Screw | | 25 | 75 | 500 | 480 (0.64) |
| Vane | | 13 | 25 | 850 | 250 (0.33) |

Table 5

# Maintenance of the hydraulic oil and the hydraulic system

## *Contaminants*

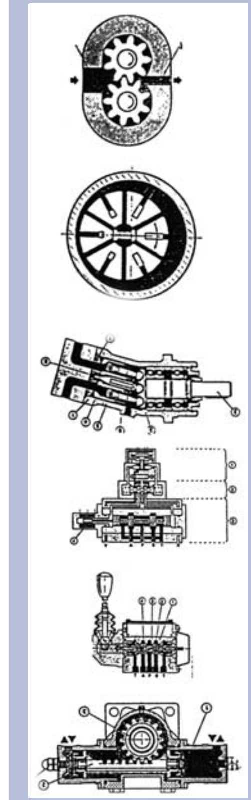
**Contaminants**
In the vast majority of cases, operating problems are caused by contaminants, either in the form of solid particles or in the form of water or different oil grades, such as engine oil.
Contamination with other oil grades can result in reduced water and air separation capacity, foaming and the formation of emulsions, as well as a risk of precipitation.
Approximately 80% of all faults in hydraulic installations are caused by solid contaminants and insufficient filtration of the oil.
These solid contaminants can cause:

- Increased friction between moving parts, which results in the components' movement being lost or becoming difficult to control
- Blocking of openings preventing the desired function
- Increased wear entails increased leakage and a reduced lifetime for machine components
- Finely distributed contaminant particles also reduce the oil's ability to separate water and have a catalytic effect on the oil's oxidation

All hydraulic systems contain larger or smaller volumes of contaminants, and this cannot be avoided. For example, one litre of hydraulic oil in a 40 litre system typically contains between 1 and 3 billion solid particles larger than 1 µm. (1 µm = 1 thousandth of a millimetre). It is possible with the naked eye to see a particle measuring 40 µm; by comparison, a human hair has a diameter of approximately 70 µm.
The size of particles that "are most dangerous" to the hydraulic system is smaller than 15 µm.
In general, it is the particularly hard particles with a size at the upper limit of the opening between moving contact surfaces that cause most damage in the system.

**Where to the particles come from?**

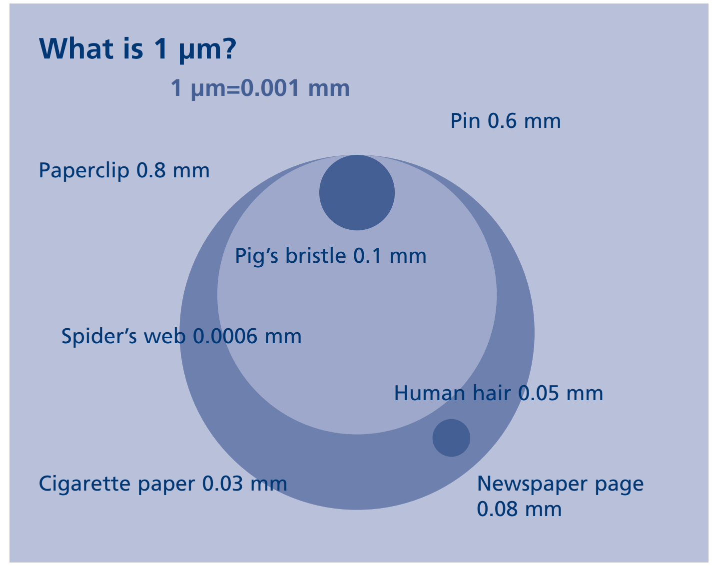
- New oil often contains more particles than sensitive equipment can tolerate, for example a high-pressure hydraulic system. Even if the oil supplier filters the oil before delivery, the packaging or the delivery method will result in the new oil have a cleanliness level of approximately 17/15/11 in accordance with ISO 4406.
- Integral particles, for example foundry sand, iron scale, dust and any other contaminants from the installation work.
- Particles that are generated in the system normally originate from the wear of the system's components (all wear produces wear particles), but can also be formed during the installation of the system.



| Component | Clearing (µm) |
| --- | --- |
| **Gear pumps** | |
| Gear to side plate | 0.5-5 |
| Gear top to outer face | 0.5-5 |
| **Vane pumps** | |
| Vane top to centre | 0.5-1 |
| Vane sides | 5-13 |
| **Piston pumps** | |
| Piston to cylinder | 5-40 |
| Cylinder block to valve plate | 0.5-5 |
| **Servo valves** | |
| Nozzles | 130-450 |
| Seat to housing/bore | 1-4 |
| **Control valves** | |
| Nozzles | 130-10,000 |
| Seat to housing/bore | 1-23 |
| Seat valves | 13-40 |
| **Starting mechanisms** | |
| Cylinders | 5-40 |
| Hydrostatic bearing | 0.5-25 |

**Fig.: Typical dynamic clearings for hydraulic components**

- Penetrating contaminants are contaminants that can enter the hydraulic oil via the air, the lubricating oil on piston rods, seals, filling with dirty oil and during maintenance work.



# Maintenance of the hydraulic oil and the hydraulic system

## *Filtering hydraulic oil*

**Specification of cleanliness degree**
The hydraulic oil's cleanliness and filtration capacity help to ensure problem-free operation. The oil's cleanliness level is traditionally specified in the form of a particle size distribution and is often assessed against one of the following standards:

**ISO 4406**
Specifies the number of particles per 100 ml of oil that are larger than 5 µm and 15 µm. Expresses the cleanliness level in a code, for example 15/12. The number 15 specifies a maximum of 32000 particles 5µm, and the number 12 a maximum of 4000 particles > 15µm.
ISO 4406 has recently been amended, and now contains 3 numbers. They specify the first number of particles > 2µm, the second number > 5µm and the third number > 15µm.
In 1999, the ISO 4406 standard was further revised, and the three particles sizes were changed to >4µm, >6µm and >14µm. In the last new system, the analysis results must be specified with (c) ISO 4406 1999 in order to make it clear that the most recent system is being used.

**ISO 4406 1999**

19/15/11

Particles > 4µm ← 19 | 15 → Particles > 6µm | 11 → Particles > 14µm

**NAS 1638**
Specifies the number of particles per 100 ml of oil in 5 different size ranges, namely 5-15µm, 15-25µm, 25-50µm, 50-100µm and > 100µm.

| System type | Pressure, Bar, max. | Desired cleanliness level in accordance with ISO 4406 | Desired cleanliness level in accordance with NAS 1638 | Recommended filtration degree µm. ($\beta x$ > 100) |
|---|---|---|---|---|
| Extremely sensitive systems with very high operational safety requirements, such as within the aeronautical and space travel industries | 600 | 14/12/9 | 3 | 1-2 |
| Demanding industrial hydraulic systems with high requirements for reliability and a long lifetime | 400 | 16/14/11 | 5 | 3-5 |
| General industrial and mobile hydraulics with non-extreme high pressure and with limited requirements for reliability | 250 | 18/16/13 | 7 | 5-15 |
| Systems with short operating times or low maximum pressure level. Agricultural machinery and construction machinery | 150 | 20/18/15 | 9 | 15-30 |
| Low pressure systems with large tolerances and direct, manually operated valves | 40 | 22/12/18 | 12 | 25-40 |



**Filtering hydraulic oil**
Particles in the hydraulic oil must be filtered out as quickly as possible, and ideally before the oil passes any sensitive components. In order for filtration to work effectively, it is necessary for filters to be positioned at strategic locations in the system and for as large a volume of the oil as possible to pass through the filter(s) per time unit.

**General functional requirements for an oil filter**
- The filter must capture as many as possible of the solid particles contained in the oil that flows through the filter, down to a certain particle size.
- A certain amount of particles must be able to be collected in the filter before the system begins to run slowly.
- It must not be possible to detach particles that have been captured by the filter.
- When the pressure drop over the filter exceeds a certain limit due to high oil viscosity (cold starts) or a clogged filter, the oil must be able to pass unfiltered through a bypass filter. Because this unfiltered oil can give rise to problems, many filters have an indicator that shows when the filter is beginning to become clogged. Other filters are calculated for a high pressure drop without rupturing and are supplied without a bypass valve.
- In some filters, a valve should prevent the oil from passing out of the filter housing after the flow of oil has stopped.
- The filter must be able to withstand a certain static pressure and must remain sealed in respect of external leakage.

The above functional requirements must be satisfied despite the loads to which the filter is subjected:

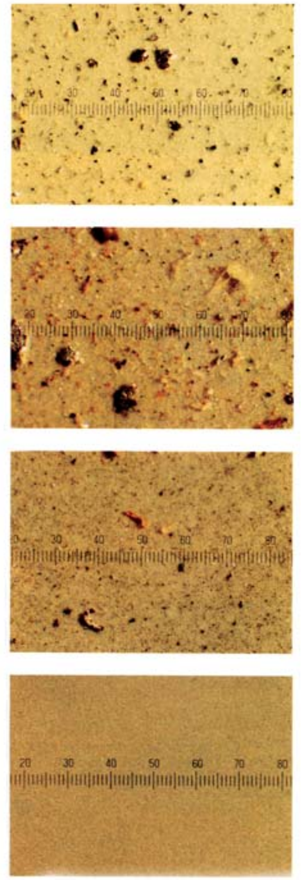
- High pressure drop over the filter
- High temperature
- Pressure increase, partly due to cold starts
- High vibration level
- Water and chemical contaminants in the oil

**Filtration degree**
The filtration degree is specified as an absolute value, an nominal value or a beta value.
The beta value is ascertained by means of a "Multipass test" (ISO 4572), the most common standardised test method for filters.

$$\text{beta (x)} = \frac{\text{Number of particles per ml} > x\ \mu m.\ \textbf{before} \text{ the filter}}{\text{Number of particles per ml} > x\ \mu m.\ \textbf{after} \text{ the filter}}$$

The particle size (x) that gives beta (x) = 75 must be specified as the filter's absolute value.

Photomicrograph (100x mag.)



# Maintenance of the hydraulic oil and the hydraulic system

## *Status check and oil analyses*

**Status check**

It is hardly economically defensible to conduct regular laboratory analyses for small systems (<250 l), and oil changes are usually carried out based on experience. Large hydraulic systems, on the other hand, often contain several hundred litres of hydraulic oil, and here it is common to check the oil's status with regular analyses. (Every 6 months, for example.)

**Visual inspection**

Weekly visual inspections are a safeguard against temporary hitches and unexpected sudden operational stoppages. Table 7 shows a schedule that can be used for such a visual inspection.

| The oil's appearance | Possible cause | Action/Recommendation |
|---|---|---|
| Light and clear | Normal | The oil can still be used |
| Cloudy, turbid | The oil is contaminated with emulsified water | Analyse/change the oil |
| Free water | The system is contaminated with water | Drain the water |
| Dark, smells burnt | The oil has oxidised | Analyse/change the oil |
| Visible contaminants | Dirt, wear particles | Analyse/change the oil/ check filter |

Table 7

**Why analyse the hydraulic oil?**

An oil analysis can give answers to the following questions:

- Is serious wear taking place?
- What type of wear?
- Where in the machinery is the wear taking place?
- Can the content of the contaminants in the oil cause problems in the future, for example abrasive wear, corrosion, valves that stick, etc.?
- Is the pipe system cleaned sufficiently well?
- Does the filtration function satisfactorily?

Regular analyses of the oil's status with regard to both particles and contaminant level, but also the oil's chemical/physical status, will provide the potential to:

- Identify mechanical problems before they become too large
- Reduce downtime
- Plan maintenance intervals
- Reduce maintenance costs
- Optimise the oil change intervals

**What analyses should be carried out?**

The following analyses are commonly carried out during a laboratory analysis of hydraulic oil:

- Kinematic viscosity at 40°C, mm²/s.
  A reduction in viscosity can indicate possible contamination with a thinner oil, a reduction in VI-improver (the polymer in the oil) or thermal degradation of the oil. An increase in viscosity can indicate possible contamination with a thicker oil or that the oil has oxidised.

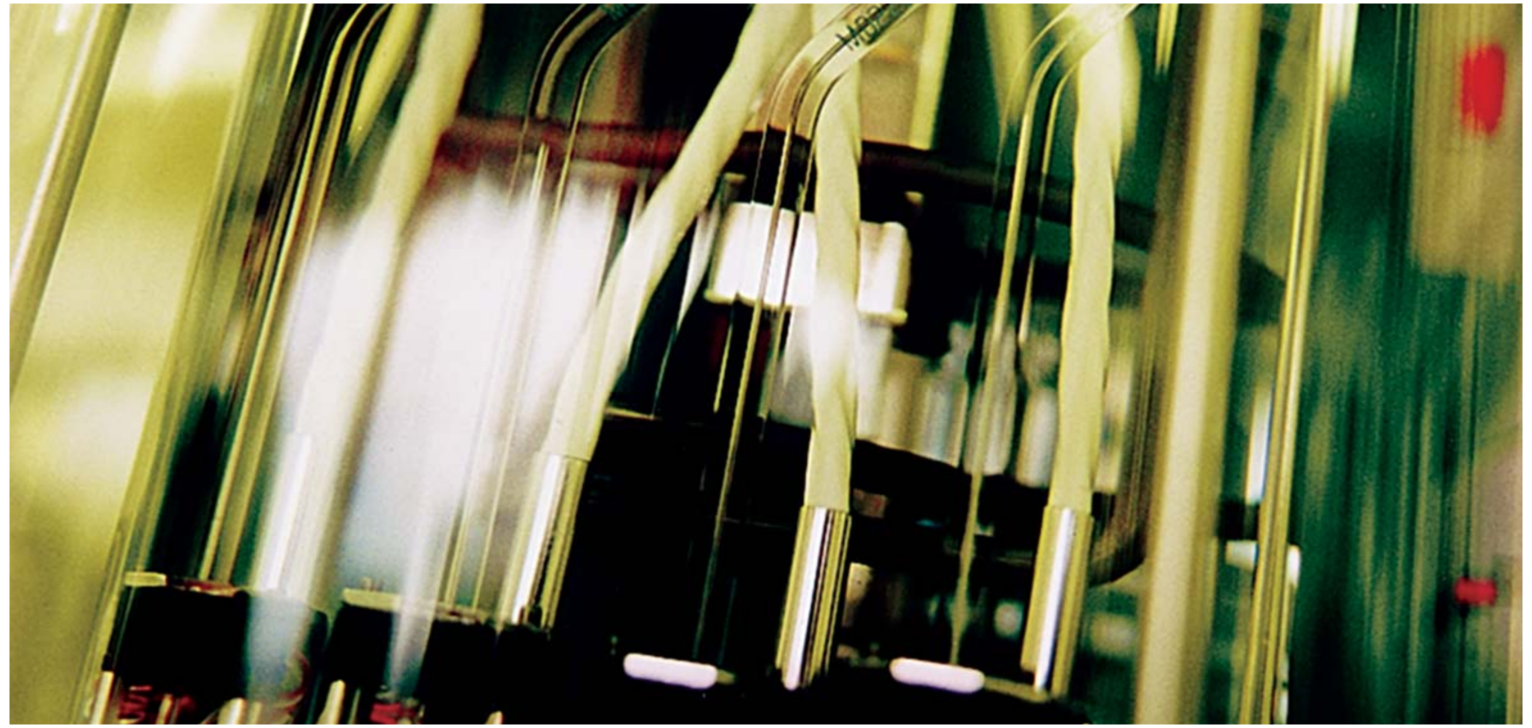
- Neutralisation value / Acid number / TAN (Total Acid Number), mg KOH/g oil. New zinc-free hydraulic oil normally has a neutralisation value of 0.15–0.2 mg KOH/g oil, and an increase indicates oxidation of the oil.

- Water content, ppm (parts per million) or % by volume. Specifies the oil's water content.

- Element analysis, ppm
  Specifies the oil's content of additive elements and wear metals. The content of additive elements is compared with the values for new oil and can demonstrate possible contamination by another oil, as well as how the additives are used over time. By following the trend for the content of wear metals, it is possible to reach conclusions about the wear in the system and possibly where in the machinery the wear is taking place.

- Particle analysis, number of particles in 100 ml of oil, expressed in ISO 4405 or NAS 1638 class.
  Specifies the degree of cleanliness of the oil.





**Conclusion of the analysis**

When an oil sample is sent to the laboratory, the conclusion of the analysis will be dependent on sufficient information having been enclosed with the sample. Statoil has therefore developed its own forms/schedule that must be filled out so that the correct information is obtained. This makes it possible to enter the analyses into an in-house computer program so that trends can be followed for the various systems on which analyses are conducted.

The analysis report will give a combined evaluation of the analysis values, and a probable cause of any problems will be presented, along with proposed measures.

# Maintenance of the hydraulic oil and the hydraulic system

## *Problems that can arise in the hydraulic system*


**Air/foam problems**
Solubility for air is relatively great in mineral oils compared with other typical hydraulic media. Despite the relatively high solubility, air is of secondary importance as long as it remains dissolved in the hydraulic oil. The amount of dissolved air increases as the pressure increases. In vacuums, the air is released in the form of air bubbles, which are then compressed on the pressure side. The temperature can then rise as high as 800°C, and at this high temperature the oil evaporates. The mixture of oil and air spontaneously combusts and the oil smells burnt.
This phenomenon is known as the diesel effect or the Lorentz effect, and corresponds to what takes place when the fuel in a diesel engine is combusted by the compression heat. The diesel effect can be detected from the noise caused by powerful blast waves. In serious cases, this can lead to cavitation, and fire damage can also arise in gaskets.

Frequent causes of foaming and circulation of non-dissolved air are:

- Leaks in the suction line, couplings, etc.
- The return oil (which usually already contains dissolved air) splashing down in the tank
- The return oil being allowed to flow unobstructed to the pump's suction line
- Low oil level, too short circulation time
- Contaminants, finely distributed particles and contamination with other oil types

The correct diagnosis and treatment of air/foam problems is important. Similarly, a correct evaluation of the causes is necessary in order for operational problems to be resolved quickly and economically.
The installation should first be checked for possible mechanical faults, oil level, etc. If no irregularities are established, oil samples should then be examined with regard to:

- Air separation, test method in accordance with IP 313, ASTM D342

- Foaming properties, test method in accordance with IP 146, ASTM D892

A new hydraulic oil contains foam-inhibiting additives: silicones. This is to prevent the build-up of foam in the oil reservoir. These additives only work against surface foam, and it is useless to overdose with this additive in a system that is drawing false air in the hope that foaming will subside. The surface-active additives will worsen the situation by having a stabilising effect on the finely distributed air bubbles and impairing the oil's ability to separate air.
Unwanted silicone can also originate from certain sealing pastes and from release agents used during the production of hoses.

# Maintenance of the hydraulic oil and the hydraulic system

## *Problems that can arise in the hydraulic system*

**Problems that can arise during oil changes/miscibility**

Even if Statoil's hydraulic oils have achieved good results when tested for miscibility with other hydraulic oils, both our own and those of our competitors, mixing should be avoided as far as possible.

When changing the oil in a hydraulic system, it is important to drain as much of the used oil as possible. However, it is not possible to remove all the oil from the system without completely dismantling it and cleaning all the parts.

Problems that can arise when mixing different hydraulic oils include a reduction in filterability, the precipitation of jelly-like substances as a result of chemical reactions between the various additives in the oils, as well as problems with foaming. All of these problems are exacerbated if the oil is contaminated with water.

When changing the hydraulic oil in a relatively large system, an analysis of the used oil should therefore be carried out in order to establish the water content and the miscibility between used oil from the system and the new oil that is to be filled.

Specific precautions must be taken in the event of a transition from mineral hydraulic oil to a biodegradable oil, and also when changing from one type of biodegradable oil to another. Details of these can be obtained by contacting the oil supplier.

If the correct precautions have not been taken when changing between two different oil grades, and problems such as those described above arise, it may be necessary to change the oil again.

It is important to be aware that problems can also arise when filling a completely new system, as the system can contain residue of oil/machining fluids left over from the testing or protection of components during production. It is therefore necessary to obtain as much information as possible about this, in order to consult with the oil supplier.

**Fault-tracing in hydraulic systems**

| Fault-tracing in hydraulic systems | Possible causes |
|---|---|
| No movement at start-up | Oil level too low<br>Fault in oil grade<br>Too high oil viscosity<br>Air in the system<br>Clogged suction filter<br>Leaking pressure control valve<br>Mechanical break in the system Worn pump |
| Too slow movement | Worn pump<br>Air in the system<br>Leak in suction line<br>Leaking suction line<br>Leaking pressure control valve<br>Worn pump gasket |
| Uneven movement | Air in the system<br>Damaged oil vibration damper<br>Too stiff<br>piston gasket |
| Movement stops during operation | Oil level too low<br>Rupture in hydraulic tube |

| Fault-tracing in hydraulic systems | Possible causes |
|---|---|
| Working pressure too low | Leaking oil pipes/<br>oil hoses<br>Leaking valve<br>Dirt in the valve<br>Worn valve<br>Defective valve seats |
| Abnormal noise in the system | Air in the system<br>Dirt in oil filters<br>Oil level too low or oil with too high viscosity<br>Insufficient oil in suction line to the pump<br>Too weak or defective spring in the relief or expansion valve |
| The oil becomes too warm | Incorrect oil viscosity<br>Dirt in the oil<br>Level too low<br>Dirt in the relief valve<br>Worn pump |
| The oil is foaming | Air in the system<br>Oil level too low<br>Incorrect oil grade<br>Contaminated oil<br>Incorrectly positioned damping plates in the tank |

Table 8