

HYDRAULIC FLUIDS & LUBRICANT
Technical Information





Introduction

The purpose of this manual is to aid the machine operator in the selection of suitable hydraulic fluid.

The specifications of the lubricant manufacturer and the recommendations of the machine manufacturer are the basis for selection and are subject to change without advance advice. The choice of suitable hydraulic fluids or lubricants is critical for the lifetime, operational safety and efficiency of **hydraulic components**.

If there are any fire hazards, see *Safety instructions*.

The selection of the appropriate hydraulic fluid for a specific application can be made only when the different features of the lubricants and the task and conditions under which the machine is to operate are taken into consideration.

Content subject to change.

History of revisions

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Safety Instructions

Health, accident and environmental measures

When operating units, which are filled with hydraulic fluids (hereafter referred to as lubricants) the operator must consider, among other things, the following precautionary measures:

- Prolonged skin contact with the lubricants is to be avoided. Careful skin cleansing of sticky fluid and regular changing of with lubricant soiled work clothes is required.
- Skin contact with fluid or with heated unit parts is to be avoided, especially at temperatures over 60 °C [140 °F].
- Should lubricant get into your eyes, rinse them thoroughly with drinking water and see a doctor if necessary.
- Official regulations must be observed when storing lubricants (e. g. fire extinguishers, emergency exits).
- Clean up spills to avoid slipping (e. g. normal commercial cleaning agents).
- Lubricants must not seep into the ground or get into the sewer system.
- Concrete floors as foundations can be protected against fluids by being sealed or being painted with fluid-resistant paint.
- The first time start up of systems filled with hydraulic fluid, all unnecessary personnel has to stay away from the system.
- Old or unusable fluids are to be collected. Quantities above 200 liters [53 US gal] are presently picked up free of charge in Germany by the authorized collectors, as long as prohibited foreign substances are not added to these.
- For safety reasons, the flash point of the hydraulic fluid should always be at least 20 °C [68 °F] above the maximum fluid working temperature.
- Current official regulations must be observed.



General Information

Hydraulic Fluid Features

Hydraulic fluids have the primary purpose of transferring potential or kinetic energy (pressure and movements), create volume flow between pump and hydrostatic motor, and reduce the wear of parts that rub against each other. In addition, they protect the system from corrosion and help carry away the heat produced during energy transformation.

The following table gives an outline of the necessary requirements for hydraulic fluids.

Necessary characteristics of hydraulic fluid

Required	Prerequisites
Volume stability	adequate capacity to separate air
Wear protection capacity	for a hydrodynamic or hydrostatic fluid layer between sliding surfaces
	adequate viscosity at operating temperature for all others wear reducing additives
Corrosion protection capacity	non-aggressive toward customary materials and rust protection additives
Desirable	Prerequisites
Only slight change in usage	adequate oxidation resistance
	for some cases of application adequate deemulsification capacity adequate shear stability, if polymer viscosity index improvers are used
Viscosity-temperature behavior	so that oil changes due to summer and winter operation become redundant
	adequately low Viscosity-Temperature behaviour
Interaction with seals / gaskets	standard sealing materials can be used
	minimal characteristics changes of standard elastomers

For most of the identifying characteristics listed in the table, there already exist standards or at least preferred testing procedures which allow a numerical classification of these identifying features.

The Turolla warranty claim policies do not apply for fluid related damage which result from mixing. It is not permissible to mix lubricants. The different additive package may cause negative interactions. If lubricants mixing can not be avoided, fluid manufacturers approval is required.

This catalog provides general information regarding hydraulic fluids.
Please refer to Turolla product technical literature for specific fluid ratings including temperature, viscosity, cleanliness, and filtration requirements.



General Information

Hydraulic fluid has to perform the following tasks:

- Energy transmission
- Lubrication
- Heat removal

When choosing a hydraulic fluid the following features are most important for consideration:

- Viscosity
- Viscosity Index (VI) and/or Viscosity Grade (VG) viscosity at 40 °C [104 °F].
- Pour point
- Shear stability, when polymer VI-improvers are used

For any application the features of the hydraulic fluid must be appropriate to the operating environment of the unit and its components.

The following is an explanation of the fundamental features of the hydraulic fluids:

Viscosity

A hydraulic fluid has a low viscosity when it is thin and a high viscosity when it is thick.

The viscosity changes with the temperature.

- If the temperature increases, viscosity is reduced.
- If the temperature decreases, viscosity is increased.

Hydraulic units work under extreme temperature changes, especially in heavy duty vehicles. The viscosity range of the hydraulic fluid is extremely important.

The hydraulic fluid must be thin enough to flow through the filter, inlet and return pipes without too much resistance.

On the other hand, the hydraulic fluid must not be too thin, in order to avoid wear due to lack of lubrication and to keep internal leakage within limits.

In the hydraulic business typically the *kinematic* viscosity ν in mm²/s [SUS] is used for calculations, mainly for calculating the pressure drop in the connecting hoses and pipes.

The other measure is the *dynamic* viscosity η in mPa s. Dynamic viscosity is used for calculating the lubricating film thickness in a journal bearing and similar sliding films between adjacent parts.

Conversion of viscosities:

Dynamic viscosity (η) = kinematic viscosity (ν) x density (ρ):

$$\eta = \nu \cdot \rho = (\text{mPa}\cdot\text{s})$$



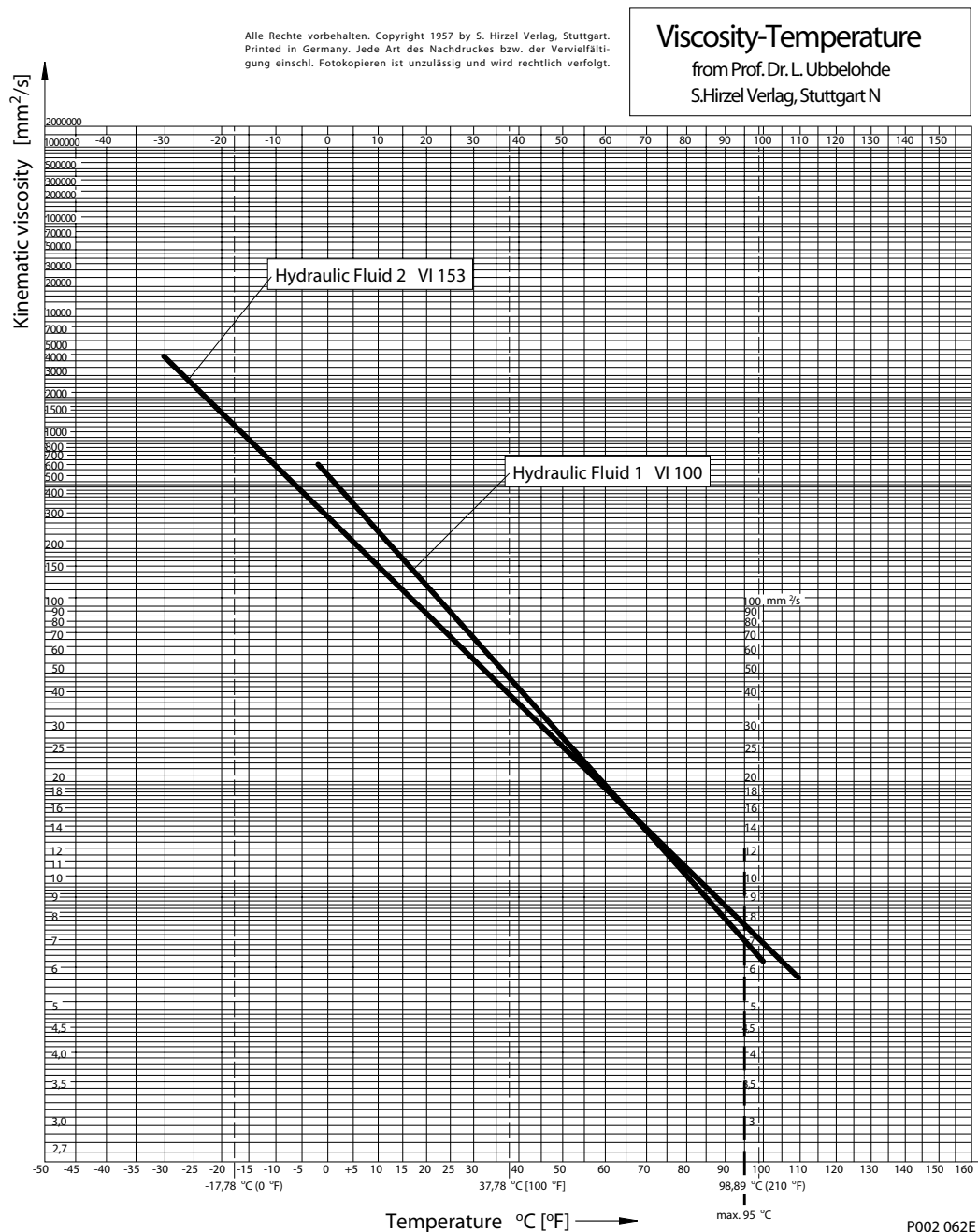
General Information

Viscosity index (VI)

The viscosity index is a calculated number, according to DIN ISO 2909 which describes the viscosity change of a mineral oil based or a synthetic fluid versus temperature.

- a **high** viscosity index means a **small** viscosity change when the temperature changes
- a **low** index means a **large** viscosity change when the temperature changes

Viscosity – temperature diagram according to Ubbelohde representing the temperature operating range of hydraulic fluids with different viscosity index (VI).



Most hydraulic fluids have a VI value of 90 - 110. Hydraulic fluids with a VI larger than 110, e.g. between 130 - 200, are not as sensitive to temperature change.



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These hydraulic fluids distinguish themselves by starting up well and having minimal loss in performance at low temperatures. At high temperatures a sufficient sealing effect and protection against wear is achieved by using hydraulic fluids with high viscosity index. The high durability of a hydraulic fluid with a high viscosity index avoids damage and machine breakdown, lowers the operating cost and increases the life of hydrostatic transmissions and units.

Shear stability

Fluids using polymer viscosity index improver may noticeably shear down (> 20 %) in service. This will lower the viscosity at higher temperatures below the originally specified value. The lowest expected viscosity must be used when selecting fluids. Consult your fluid supplier for details on viscosity shear down.

Pour point

The pour point according to ISO 3016 defines the temperature when the fluids stops to flow. Start up temperature is recommended to be approximately 15 °C [59 °F] above hydraulic fluid pour point.

Density

The density has to be specified by the manufacturer of the hydraulic fluid. Using hydraulic fluid with a high density requires the sufficient diameter of the suction line and/or elevated tank to provide positive inlet pressure.

Sealing compatibility

In general NBR (Nitrile) or FPM (Fluorocarbon, Viton) is used as seal material for static and dynamic seals. For mineral based hydraulic fluids, both seal materials are suitable. Please contact your Turolla representative regarding seal compatibility with specialty fluids.

Air in the hydraulic fluid

Free air is considered as contamination as well. Air typically enters the circuit through the suction line if the seals and fittings are not tight. This free air then may be dissolved in the hydraulic fluid. Mineral based hydraulic fluid may contain up to 9 % volume percent dissolved air at atmospheric pressure. If 1 l [0.264 US gal] of hydraulic fluid is compressed to 100 bar [1450 psi], it may dissolve 9 l [2.377 US gal] of free air if offered.

This is not a problem unless the pressure drops down quickly to a lower level. Then the air becomes free again and bubbles show up. These bubbles collapse when subjected to pressure, which results in cavitation which causes erosion of the adjacent material. Because of this, the greater the air content within the oil, and the greater the vacuum in the inlet line, the more severe will be the resultant erosion. The bubbles may also result in a spongy system, slow response time, and poor controllability. Therefore care must be taken to avoid air to enter the system. If air has entered a system the air release time and foam characteristic becomes important.

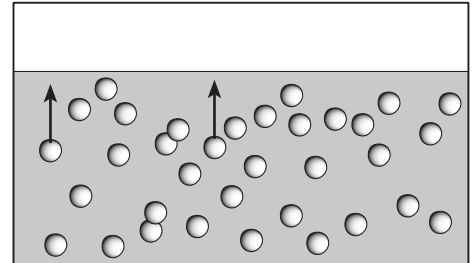


General Information

Air release

Air release is a measure for the time needed to release air bubbles (free air) contained in the fluid to the surfaces. Air typically enters the circuit through the suction line if the seals are not tight as explained above.

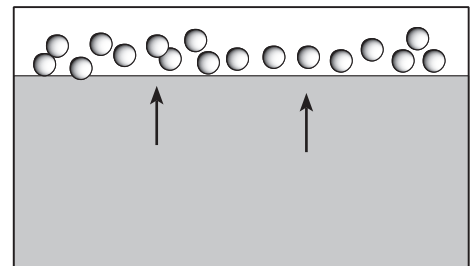
Air release time is tested according to DIN 51 381.



Foaming characteristic

Foaming characteristic defines the amount of foam collected on the surface in the reservoir and the air bubble decomposition time. Foaming may become a problem when air has entered the circuit as explained above, through an insufficient tight suction line.

The foaming characteristic of a hydraulic fluid is tested according to DIN 51 566 .



Bulk modulus/Compressibility

While fluids are usually considered incompressible, the pressures that can occur in hydrostatic systems are of a magnitude that fluid compressibility can be significant. In applications that experience system pressure fluctuations resulting in random high pressure rise rates, consideration must be given to fluid compressibility when sizing a charge pump to ensure adequate charge pressure.

The amount that a specific fluid compresses for a given pressure increase is related to a fluid property known as the bulk modulus. The bulk modulus is a measure of a fluids resistance to being compressed. It depends on pressure and temperature. The air content is important as well especially below 50-100 bar [725-1450 psi]. The higher the air content the more spongy the system (lower bulk modulus). For a given pressure increase and fluid volume, a fluid with a large bulk modulus will experience a smaller reduction in volume than a fluid with a low bulk modulus.



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Mathematically, bulk modulus is defined as follows:

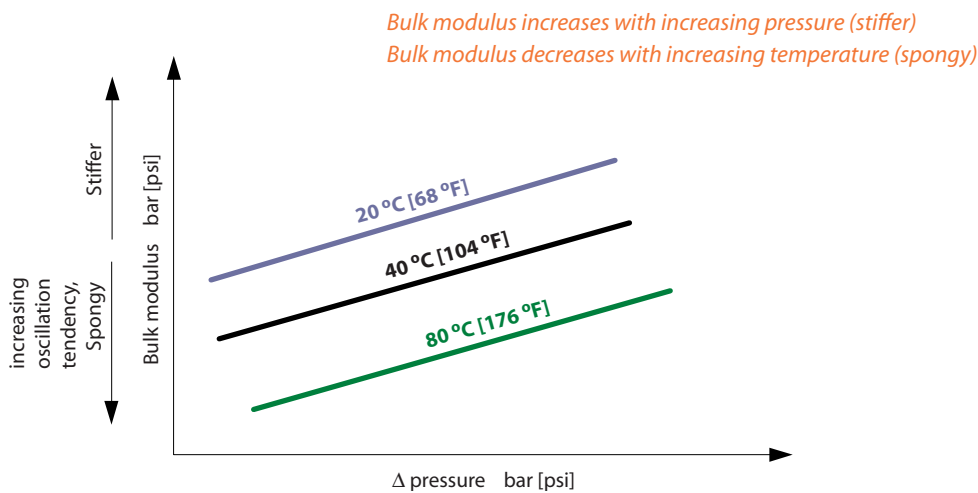
$$E = \frac{\Delta \text{ pressure} \times \text{initial Volume}}{\Delta \text{ Volume}} = \frac{\Delta p \cdot V_0}{\Delta V} = \text{bar [psi]}$$

where:

E	=	bulk modulus of the fluid	bar [psi]
Δp	=	change in pressure	bar [psi]
ΔV	=	change in volume	l [US gal]
V_0	=	volume of oil experiencing the change in pressure	l [US gal]

Units for bulk modulus are the same as the units for pressure.

Bulk modulus vs. Δ pressure for different temperatures



Another term often used is compressibility. It defines how much a fluid can be compressed. Compressibility is the reciprocal of the bulk modulus.

$$\text{Compressibility} = \frac{1}{E} = \frac{\Delta V}{\Delta p \times V_0} = \text{bar}^{-1} [\text{psi}^{-1}]$$



General Information

Examples for bulk modulus and compressibility at 22 °C [71.6 °F] and 140 bar [2031 psi] and 300 bar [4351 psi]

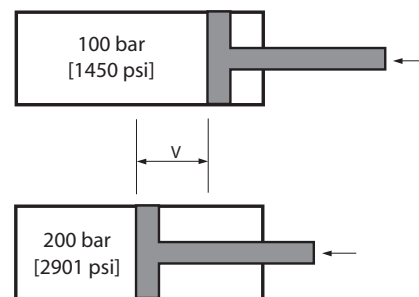
	Bulk Modulus bar ⁻¹ [psi ⁻¹]		Compressibility bar ⁻¹ [psi ⁻¹]	
	140 bar [2031 psi]	300 bar [4351 psi]	140 bar [2031 psi]	300 bar [4351 psi]
Water	11 000	15 000	91 x 10 ⁻⁶	67 x 10 ⁻⁶
Mineral based hydraulic fluids	15 000	16 000	67 x 10 ⁻⁶	63 x 10 ⁻⁶

Fluid compressibility becomes a concern for a hydrostatic system which has large volumes of oil under pressure, such as long or large system lines, and experiences high system pressure spikes during operation.

To understand the nature of the problem that can be associated with fluid compressibility, consider what happens when a system experiences an increase in load. An increase in load requires more torque from the motor, and consequently, an increase in system pressure. When the system pressure increases, the fluid in the high pressure side of the hydrostatic loop is compressed.

The illustration beside shows a simple model consisting of a cylinder whose piston compresses the fluid to create a pressure of 100 bar [1450 psi]. If a load forces the piston to move a small distance to the left, the fluid compresses even more, resulting in the pressure increasing to 200 bar [2900 psi].

The fluid at this pressure now occupies a smaller volume than the fluid did at 100 bar [1450 psi]. At the same time, the volume on the rod side of the piston increases. If we imagine that the rod side of the piston is also filled with fluid, then a void is created on this side of the piston when the fluid against the piston face is compressed. To keep the rod side of the piston full of fluid, additional fluid must be added to this side of the piston.



Calculation:

The hydraulic fluid volume under pressure in the cylinder is 10 l [2.64 US gal]. As approach the bulk modulus for 140 bar [2031 psi] as shown above is used.

$$\Delta V = \frac{\Delta p \cdot V_o}{E} = \frac{(200-100 \text{ bar}) \cdot 10 \text{ l}}{15\,000 \text{ bar}} = 0.067 \text{ l [0.0176 US gal]}$$



General Information

Cleanliness Features

Definition of cleanliness levels per ISO 4406

The cleanliness level of a hydraulic fluid is determined by counting number and size of particles in the fluid. The number of particles is defined as a cleanliness level according to ISO 4406.

Definition of cleanliness levels per ISO 4406

Number of particles per 100 ml	Number of particles per 1 ml	Cleanliness levels per ISO 4406
1-2	0.01 - 0.02	1
2-4	0.02 - 0.04	2
4-8	0.04 - 0.08	3
8-16	0.08 - 0.16	4
16-32	0.16 - 0.32	5
32-64	0.32 - 0.64	6
etc.	etc.	etc.
$4 \times 10^3 - 8 \times 10^3$	40 - 80	13
$8 \times 10^3 - 16 \times 10^3$	80 - 160	14
$16 \times 10^3 - 32 \times 10^3$	160 - 320	15
$32 \times 10^3 - 64 \times 10^3$	320 - 640	16
$64 \times 10^3 - 130 \times 10^3$	640 - 1300	17
$130 \times 10^3 - 250 \times 10^3$	1300 - 2500	18
$250 \times 10^3 - 500 \times 10^3$	2500 - 5000	19

The step to the next cleanliness level means double or half the number of particles.

The old ISO 4406-1987 defines the cleanliness level of particles larger than 5 μm and 15 μm . As an example: if 1910 particles/ml larger than 5 μm and 71 particles/ml larger than 15 μm are counted, the ISO 4406-1987 code level is 18/13.

In 1999 both, the definition for particle counting and the definition of ISO code was changed. The required cleanliness class definition is now determined by ISO 4406-1999. The allocated particle sizes are:

Comparison of old and new standard ISO 4406

Old ISO 4406-1987	New ISO 4406-1999
not defined	4 μm (c)
5 μm	6 μm (c)
15 μm	14 μm (c)

Please note, that "(c)" must be added to the new definition in order to identify that it is the new ISO 4406. The old method for particle counting may still be used.

The ISO 4406-1999 cleanliness class 22/18/13 means:

22 specifies the number of particles larger than **4 μm (c)**,
18 specifies the number of particles larger than **6 μm (c)**, and
13 specifies the number of particles larger than **14 μm (c)** related to 1 ml respectively 100 ml of the inspected fluid.

The new method counts more smaller particles and less larger particles.

For better understanding please see *the graph beside*.

This graph demonstrates the effect of the change to the new particle sizes 4 μm (c), 6 μm (c), and 14 μm (c).



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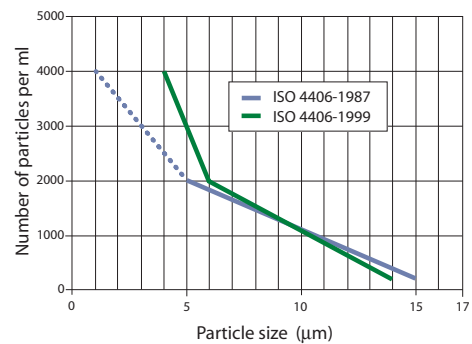
Measurements with the same fluid sample will result in the same cleanliness class for both methods as shown *in the table below*.

Number of particles per milliliter, particle count comparison

Particle size	1 μm	4 μm (c)	5 μm	6 μm (c)	14 μm (c)	15 μm
Not standardized	4000	-	-	-	-	-
Old ISO 4406-1987	-	-	2000	-	-	180
New ISO 4406-1999	-	4000	-	2000	180	-
ISO 4406 cleanliness class	19	19	18	18	15	15

Again, the actual number of particles of a sample is of course the same, only the counting method is different. Although it may look like, the new method does not allow more particles!
 Together with this ISO 4406 change a new calibration standard ISO 11 171-1999 and a new Multipass test ISO 16 889-1999 for filters have been developed.

ISO 4406-1999 versus prior cleanliness classes



Comparison of old and new standards

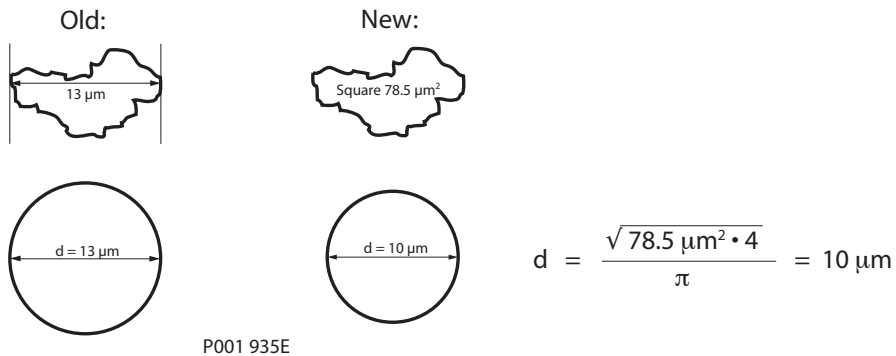
Old standards	Test description	New standards
ISO 4402-1991	Automatic particle counter (APC) calibration	ISO 11 171-1999
ISO 4406-1987	Cleanliness code	ISO 4406-1999
ISO 4572-1982	Multipasstestforfilters	ISO 16 889-1999



General Information

New particle size definition

The particle size definition has been changed also. The old standard defined the largest particle extension as the particle size. The new standard uses the projected square area and converts this to an equivalent diameter. Please see *the picture below*.



ISO 4407 (under revision) specifies particle counting with a microscope. Only particles larger 5 μm and 15 μm are manually counted and specified as -/18/13. The “-” is used in place of the first scale number, while 18 is allocated to 5 μm and 13 to 15 μm.



Requirements for Hydraulic Fluids

Technical Requirements of Hydraulic Fluids

Water content per DIN ISO 3733

In a new fluid the water content must be out of the quantitative detectable range. Unless otherwise specified in individual fluid standards the water content for continuous operation must not exceed 0,1 % (1000 mg/kg). The lower the better. In principle water is a harmful contaminant, reducing the life of the hydraulic fluid and the mechanical components. Water in a system may result in corrosion, cavitation, and altered fluid viscosity. Depending on the fluid, water may also react with the fluid to create harmful chemical by-products or destroy important additives. Left unchecked, water contamination may result in microbial growth. At this stage, system components may already have been damaged.

Air content

Air in a system is also regarded as a contaminant. Air increases the compressibility of the fluid, resulting in a "spongy" system that is less responsive. Also air creates a loss of transmitted power, higher operating temperatures, increased noise levels, and loss of lubricity.

Fluid change intervals

Turolla recommends the following fluid change intervals for all fluids except those mentioned below:

- First change: 500 operating hours after start up
- Second and subsequent change every: 2000 operating hours or once a year

This recommendation applies for most applications. High temperatures and pressures will result in accelerated fluid aging and an earlier fluid change may be required.

At lower fluid pressure loads longer change intervals are possible. Therefore we suggest taking a sample of the fluid at least one time, preferably more, between scheduled fluid changes. This fluid sample then can be sent to the fluid manufacturer for an analysis and a determination of its suitability for continued use.



Requirements for Hydraulic Fluids

Traces of wear metals and contamination

Wear metals are the result of corrosive wear due to water and acids but also abrasive wear due to surface roughness metal contact leading to welding. The table below shows typical amount of wear metals. In some mobile applications for copper numbers up to 300 mg/kg and aluminum up to 80 mg/kg have been found.

These metal traces are determined by Atom-Emission-Spectroscopy (AES) according to E DIN 51 396 and ASTM D5185-97. Typically particles smaller than 5 µm are detected. Larger particles are discussed below in the fluid cleanliness requirements section.

These metal traces may increase during operation. It is therefore important to monitor the wear metal concentration during operation. A sudden increase is an indication for a soon wear failure or that parts have been already damaged.

Typical values for traces of wear metal in hydraulic systems (mg/kg)

Fe	30	Sn	10	Ni	2	Pb	15
Cr	10	Al	10	Cu	50	Mo	5

Silicium (Si) has the highest percentage in dust and is contamination in a system. Silicium is very abrasive and a fluid change is recommended if 10–15 mg/kg are exceeded.

Fluid cleanliness requirements

To achieve the specified unit life, the required cleanliness level as described in the product literature must be maintained. Fluid samples shall be taken at the entry to the pump which is typically the suction line.

These cleanliness levels can not be applied for hydraulic fluid residing in the component housing/case or any other cavity after transport.

In general for fluid change and new fluid top up minimum cleanliness class 23/21/15 and for first machine start up at the factory minimum cleanliness 25/22/17 must be met if not otherwise specified. Exceeding these levels may result in start-up damage.

The before mentioned requirements reflect the experience gained from a broad range of applications. For very high lifetime requirements or contamination sensitive components (e.g. servo valves) better cleanliness levels are necessary.

Viscosity and temperature limits

When using hydraulic fluid the viscosity and temperature limits in the table below are to be observed. Under normal operating condition it is recommended to keep the temperature in the range of 30 °C to 60 °C. Fluid temperature affects the viscosity of the fluid and resulting lubricity and film thickness. High temperatures can also limit seal life, as most nonmetallic materials are adversely affected by use at elevated temperatures. Fluids may break down or oxidize at high temperatures, reducing their lubricity and resulting in reduced life of the unit.

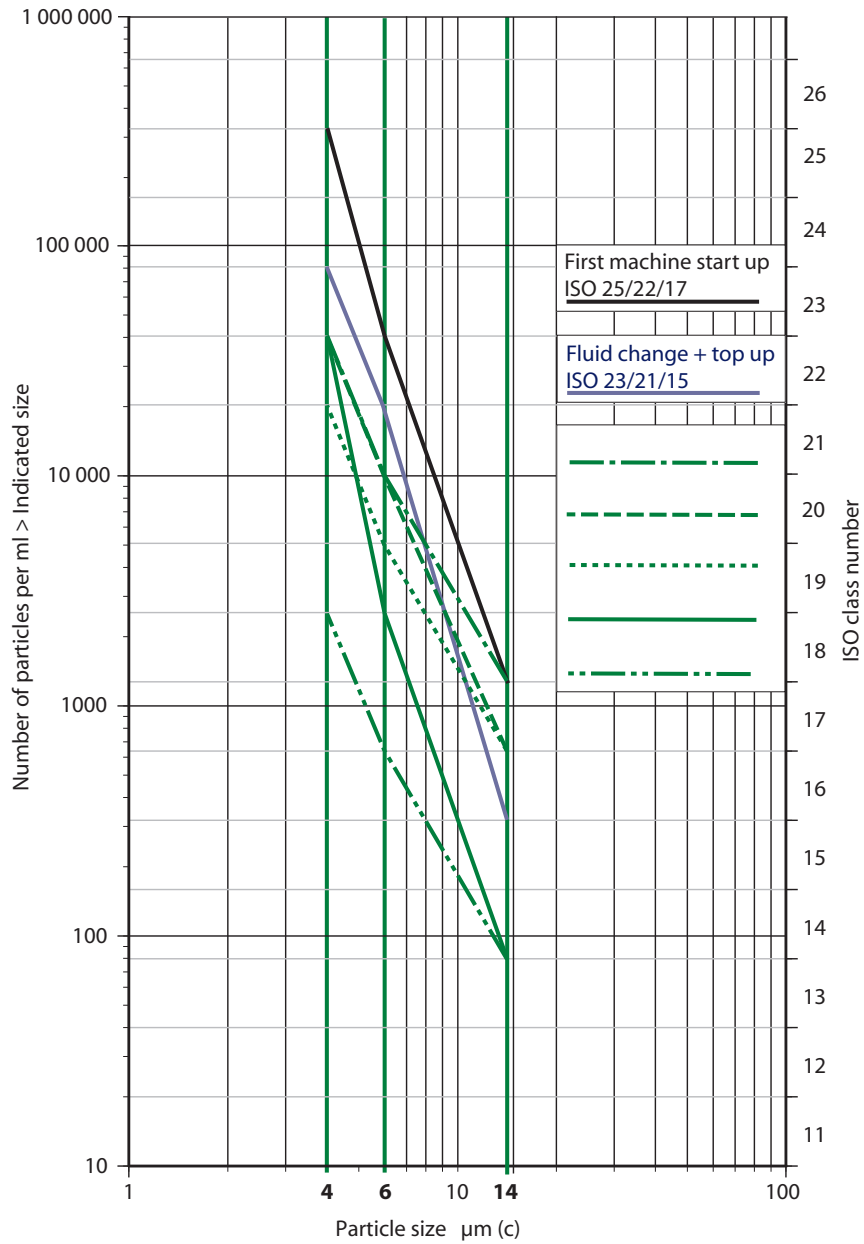
As a rule of thumb, fluid temperature increase from 80 °C [176 °F] to 90 °C [194 °F] may reduce fluid life by 50 %.



Requirements for Hydraulic Fluids

Required fluid cleanliness diagram

**ISO Solid Contaminant Code per ISO 4406-1999
(Automatic Particle Counter (APC) calibration per ISO 11 171-1999)**





Requirements for Hydraulic Fluids

Mineral Based Hydraulic Fluids

Turolla hydrostatic components may be operated with a variety of hydraulic fluids. The rated data which we publish in our Technical Information and Service Manuals are based on the use of premium hydraulic fluids containing oxidation, rust, and foam inhibitors. These fluids must also possess good thermal and hydrolytic stability to prevent wear erosion, and corrosion of the internal components. For some applications good anti-wear additives are required.

Fluids meeting these requirements will very likely provide acceptable unit life, but field testing is the only truly indication of fluid performance.

The Turolla warranty claim policies do not apply for fluid related damage.

It is not permissible to mix hydraulic fluids. The different additive packages may cause negative interactions. If hydraulic fluid mixing can not be avoided, fluid manufacturers approval is required. The Turolla warranty claim policies do not apply for fluid related damage which result from mixing.

! Warning

Turolla gear pumps and gear motors may not be used with fire resistant fluids.

Fire Resistant Hydraulic Fluids

The high water content in fire resistant fluids can cause wear and chemical reaction with aluminum components and other soft metal components such as wear plates and journal bearings.

Biodegradable Hydraulic Fluids

The growing environmental awareness has increased the research and development for biodegradable hydraulic fluids. Although these fluids have improved over the last years these are not yet ready to replace mineral based hydraulic fluids. Still several performance issues need to be improved. Many product ratings such as temperature, viscosity, speed and pressure need to be derated to ensure acceptable performance and life with biodegradable fluids.

Since long term experience is not yet available on the application of biodegradable hydraulic fluids, Turolla does not guarantee operation of these fluids for every application and recommends thorough field testing of the fluid in questions. Before using a biodegradable hydraulic fluid, please contact your Turolla representative.

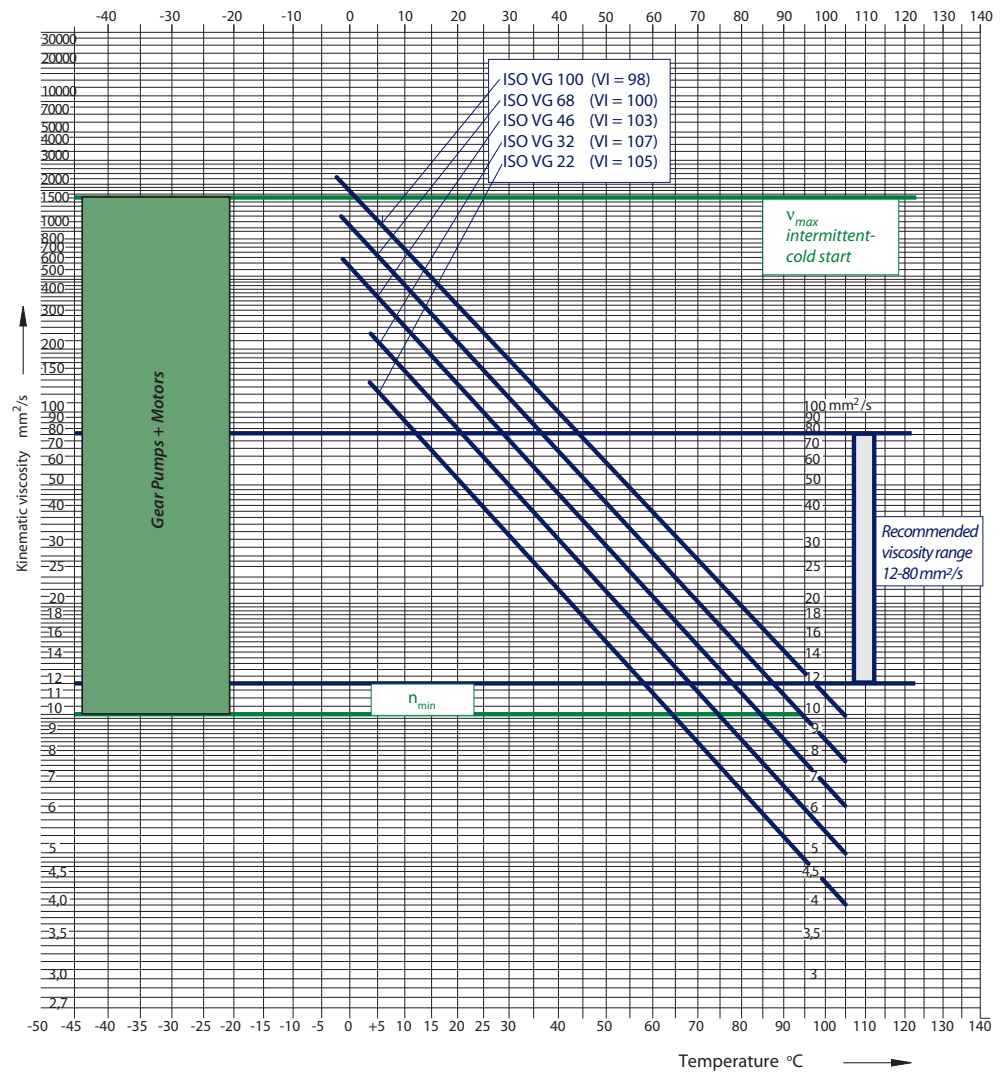
For high performance installations we recommend thorough field testing of the fluid in questions.



Requirements for Hydraulic Fluids

Hydraulic Fluid Diagram According to DIN 51 524-2 HLP

Viscosity – Temperature diagram



Shown viscosity characteristics are for reference only. Please check actual viscosity with fluid manufacturer.

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