your global specialist

Special knowledge

Geared up for success.

Useful information on oil lubrication of gears

Gear oils made by Klüber Lubrication

Increasing demands on the gear and the lubricant

Today, demands for the transmission of ever growing power and torque in gears of all performance grades in combination with reduced size and weight require new gear designs, new materials, improved surface treatment, modern production techniques as well as the application of mineral and synthetic high-performance lubricants.

As the power-to-weight ratio of the gears is increased, demands on the lubricants are becoming tougher as well. This particularly applies to their wear-reducing and anti-fretting effects as well as to their stability under high gear temperatures. The heat generated during operation must be removed via decreasing housing surfaces areas.

This results in higher operating temperatures, which affect the useful life of both the gearbox and the lubricants.

Fit for new challenges

Based on more than 80 years of experience, the experts at Klüber Lubrication have developed gear oils which meet the latest requirements to be fulfilled by the lubricant as a “design element”.

Klüber Lubrication’s high-performance gear oils are the response to unacceptably high wear rates and low gear efficiency, which substantially affect production costs. Powerful lubricants with above-average performance help to keep wear low and increase the efficiency, reducing operating costs and asset replacement. Klüber has combined the requirements of today’s power transmission technology in an approach named KlüberComp Lube Technology. We deal with gear components, lubricant composition and services in a holistic review rather than as separate topics. So for you as a gear manufacturer or operator, KlüberComp Lube Technology can help to bring a substantial increase in gear performance.

Your global specialist!

We are where you are. Our specialists are there to support you, wherever you need them. We help you select the right product or develop a solution tailored to your requirements.

“Made by Klüber Lubrication” stands for a consistent high quality level worldwide. We assure you that all our products are made to the same high quality, no matter whether produced in Asia, Europe or the Americas.

Think about tomorrow today!

Using a high-performance lubricant in times of growing environmental awareness contributes to increasing efficiency, saving energy and reducing CO_2 emissions.

The longer oil life that can be achieved leads to lower total lubricant consumption and hence less used oil disposal. There is less strain on natural resources, and both maintenance and disposal costs are reduced.

We are at your side – right from the start

With this brochure, we would like to provide you with valuable information on the lubrication of gears. We know that this is a complex issue, and therefore we offer you expert consulting – right from the start. You can take our word for it.

Selection of the right gear oil

Maximum operational reliability throughout a gearbox's service life can only be ensured if lubricants are not only considered necessary operating materials but are taken into account during all design phases as integral structural elements. Ideally, the lubricant should be selected in the design phase of the gear.

This brochure describes in a few steps how to select the right gear oil. For special applications, however, e.g. where very long service intervals are to be expected, or where operating conditions are very special, you should consult with the experts from Klüber Lubrication. They will help you utilise all of your application's potential by using the ideal lubricant.

Hint: The more we know about your application, the better can we determine which lubricant is the optimum choice in your case.

For selecting the right oil for your gears, parameters like performance, speeds, environmental influences and special operating conditions have to be taken into consideration. Based on such information, it is possible to select the

– oil type
– wear protection
– and the viscosity

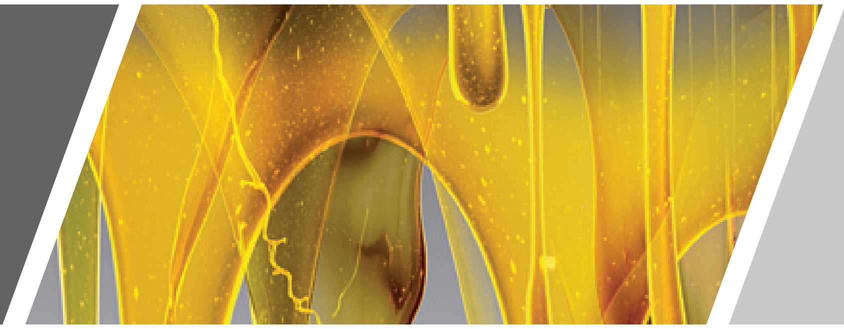
which enables the gear oil to perform its tasks to the optimum, which include:

– absorb forces
– reduce friction
– minimise wear
– dissipate heat
– absorb wear and contamination

Properties of gear oils

Gear oil properties are determined by the base oil and the additives. The essential requirements on gear oils are described by leading gear manufacturers in international standards and specifications. They include:

– Operating temperature range
– Viscosity
– Ageing behaviour
– Low-temperature behaviour
– Corrosion protection on steel / nonferrous metal
– Foaming behaviour
– Elastomer compatibility
– Compatibility with interior coatings
– Wear protection – fretting, micropitting



Operating temperature

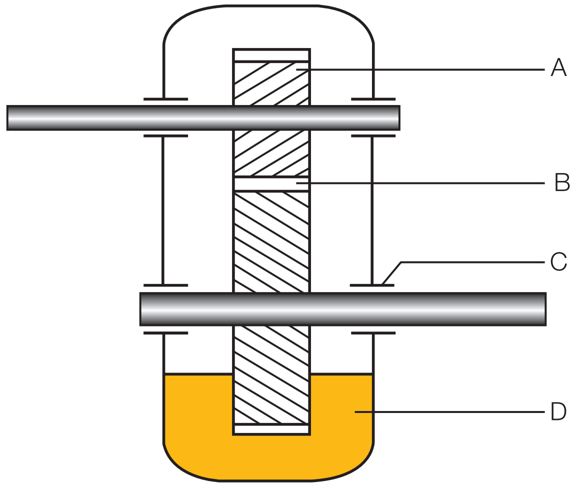
The oil temperature in industrial gears is between 20 and 150 °C, depending on the type of gear and the application. Heating of a gear system, in particular of the gear wheels, bearings and the lubricant, is one of the most important criteria to evaluate the gear's performance. The existing temperatures are indicative of the power losses.

Apart from design-related influences, oil temperatures mainly depend on the operating conditions. Oil temperatures rise with an increasing ambient temperature and when the oil is exposed to thermal radiation. They do not become quite as high when the gear is operated under partial load conditions or intermittently. It is important to ensure that the permissible temperature limits are not exceeded in individual gear components, the lubricant and the accessories (filters, pumps etc.). For viscosity selection, the oil sump temperature or temperature of the injected oil is an important factor.

Operating temperatures above average or temperature peaks often indicate malfunctions or incipient damage.

Hint: When using mineral oil-based gear oils, an oil temperature of 75 - 80 °C should not be exceeded.

Temperatures typically found in a gear



A	Mass temperature of the gear
B	Temperatures in the mesh
C	Bearing temperature
D	Oil sump temperature

Selection of the right gear oil

Viscosity

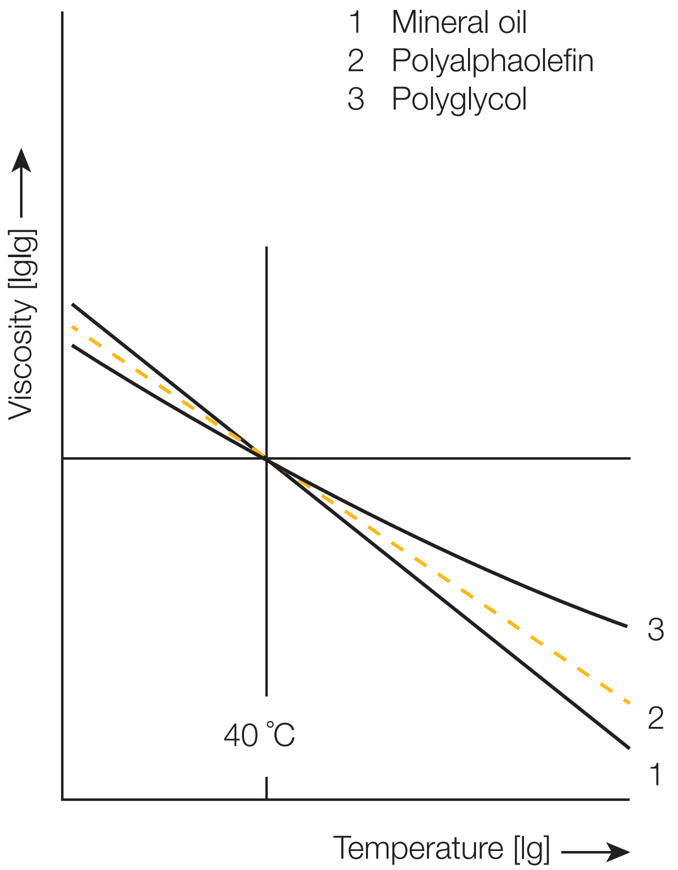
Viscosity is of primary importance when selecting gear oils, as it significantly determines the formation of a lubricant film. Increasing viscosity of the lubricating oil results in thicker lubricant films, thus improving the antiwear and damping properties as well as scuffing load capacity.

Viscosity decreases with increasing temperature and rises with increasing load. If the viscosity is too high, increased churning and squeezing losses can result in excessive heat, especially at elevated peripheral speeds. If the viscosity is too low, mixed friction conditions prevail and will result in increased wear.

Viscosity is highly influenced by temperature. The change in viscosity with temperature is usually determined by means of the viscosity index (VI). The higher the VI of a gear oil, the less viscosity changes with temperature, i. e. the flatter the VT (viscosity-temperature) curve.

The degree to which viscosity changes with temperature depends on the base oil type, such as mineral oil, polyalphaolefin, ester, polglycol, as well as on the VI improver additives contained in the lubricant.

Viscosity-temperature behaviour of oils



Comparison of viscosity indexes:

Mineral oil	VI	approx. 85 to 100
Polyalphaolefin	VI	approx. 130 to 160
Polyglycol	VI	approx. 150 to 260

Hint: A high viscosity index facilitates start-up at low outside temperatures, reduces power loss to a minimum and enables the formation of a load-carrying lubricant film also at high temperatures.

Ageing behaviour

An oil's chemical structure continuously changes when it is subjected to high temperatures, mixed with air or in contact with metal catalysts like copper, iron and others, causing it to age. The speed of the ageing process primarily depends on the oil's structure and the amount and duration of heat to which the oil is subjected. Also, contaminants like water, rust or dust contribute to oil ageing. By adding special additives the lubricant manufacturer can retard the ageing process effectively.

Oil ageing is indicated by a change in viscosity, formation of acids enhancing corrosion and residues. Residues caused by ageing occur in the form of lacquer, sludge or gum, which may clog oil lines, injection nozzles and filters,

Ageing has a negative effect on the oil's demulsifying capacity, its foaming behaviour, its anticorrosion and wear protection, and, to a certain extent, its air shedding capacity:

The ageing behaviour of oils is determined according to ASTM D 2893.

Hint: Synthetic oils show significantly better ageing resistance than mineral oils under comparable operating conditions, which is why they achieve longer oil change intervals.

Low-temperature behaviour

Depending on the base oil type, lubricating oils solidify at low temperatures as their viscosity increases, or due to wax crystallisation of the contained paraffins.

An oil's pour point is indicative of its cold flow behaviour, which is determined according to ISO 3016. The pour point is the lowest temperature at which the oil still flows when it is cooled down under specified test conditions. In order to ensure rapid and sufficient lubricant supply during a cold start, the lowest temperature occurring in a gear (starting temperature) should always be several degrees above the pour point.

Synthetic gear oils show a much better cold flow behaviour than mineral oils. Due to their high viscosity index (VI), synthetic oils are less viscous at lower temperatures than mineral oils with the same nominal viscosity. Their pour point is much lower, sometimes even below –50 °C.

Hint: Due to their good cold start behaviour, synthetic gear oils are particularly suitable for very low temperatures.

Comparison of the low-temperature behaviour of mineral and synthetic gear oils

Product	Oil type	ISO VG ISO 3448	Viscosity index ISO 2909	Pour point ISO 3016 [°C]
Klüberoil GEM 1-220 N	Mineral oil	220	≥ 90	≤ –10
Klübersynth GEM 4-220 N	Polyalfaolefin	220	≥ 150	≤ –40
Klübersynth GH 6-220 Klübersynth UH1 6-220	Polyglycol	220	≥ 220	≥ –35

Selection of the right gear oil

Anti-corrosion properties

Anti-corrosion properties of gear oils are assessed individually for:

– corrosion protection on steel
– corrosion protection on copper
(compatibility with nonferrous metals)

Corrosion protection on steel

If there is water in the system, due to either leakage or condensation, it will combine with ambient oxygen and lead to rust forming on inadequately protected steel surfaces.

Corrosion on components or rust particles contained in the oil are returned to the mesh zone and the bearings, where they have an abrasive effect and promote wear. Rust also affects ageing stability and demulsification of gear oils, and may result in the formation of sludge.

To enhance their rust-prevention properties, gear oils contain polar rust inhibitors forming a compact and protective, water-repelling layer. The gear oil's steel corrosion protection properties are determined according to ISO 7120.

Corrosion protection on copper (compatibility with nonferrous metals)

For gear oils containing EP (Extreme Pressure) additives, it is vital they do not have a corrosive effect on nonferrous metals, especially on copper or copper alloys like bronze and brass. The corrosion behaviour of gear oils is tested according to ISO 2160 using a copper strip.

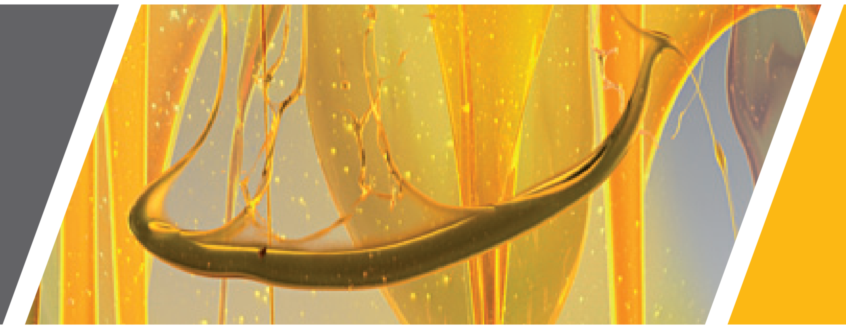
Hint: When using a gear oil for components made of or containing copper, like brass or bronze, it should pass the copper corrosion test according to ISO 2160 with the rating 1a or 1b.

All gear oils from Klüber Lubrication which comply with the requirements of DIN 51517 for CLP lubricating oils are not corrosive on copper and prevent corrosion on steel.

Compatibility with interior coatings

Gear housings made of grey cast iron or steel are usually coated to protect them against corrosion during storage, transport or extended periods of standstill.

The primers commonly used for interior coating are resistant to mineral gear oils up to 100 °C. However, they are not always resistant at higher oil temperatures (> 100 °C) or to synthetic gear oils, especially those based on polyglycol. The coatings may get soft, dissolve or form blisters and chip off, causing gear malfunctions or damage by clogging oil lines, filters and deaeration holes. Two-component coatings based on epoxy resins normally are resistant to all oil types, even at high operating temperatures. We recommend to have the paint manufacturer carry out compatibility tests prior to series application.



Foaming behaviour

Gear oils should be able to separate dispersed air rapidly and prevent the formation of stable surface foam. Foam is generated by air bubbles rising to the surface. The bubbles should burst as quickly as possible to keep foam to a minimum.

Particularly in case of splash-lubricated gears operating at medium to high peripheral speeds, the oil has a pronounced foaming tendency due to the air constantly introduced. Contaminants such as water, dust, corrosion particles and ageing residues may even increase the foaming tendency. Foaming has a strong negative impact on the lubricant's properties, such as oxidation stability, heat dissipation, etc. Excessive foaming may cause the foam to be forced out of the breather vent; in case of force-feed lubrication there is the danger of foam being drawn into the oil pump causing noise or damage.

The oil manufacturer can reduce the foaming tendency by adding anti-foam additives. However, too high a concentration may affect the air shedding capacity. The foaming tendency of a lubricating oil is determined according to ISO 6247 or ASTM D 892.

A more practice-oriented approach is the Flender foam test according to ISO 12152, which is increasingly gaining in importance. In this test, the gear pair runs in the oil, thus entraining air into the oil. Then the oil is checked for air absorption, formation of oil-air dispersion, surface foam and the degree to which these phenomena are reversible.

Gear oils made by Klüber Lubrication meet the stringent requirements of the Flender foaming test.

Selection of the right gear oil

Elastomer compatibility

The materials used for radial shaft seals (RSS) or static seals, e.g. O-ring seals, must not become brittle or softer when exposed to gear oil, as otherwise their sealing capacity would be affected. The seals would suffer premature wear, leading to leakage. Cleaning and possibly expensive gear repairs would become necessary.

Especially when higher torques lead to higher operating temperatures, or when a gearbox is changed from mineral to synthetic oil lubrication, compatibility with the seals should be considered.

The tests used for verifying the static and dynamic compatibility of gear oils with elastomers are based on ISO 1817 and DIN 3761, respectively.

Through the Lube&Seal program jointly run by Klüber Lubrication and Freudenberg Sealing and Vibration Control Technology, gear oils made by Klüber are now designed to match radial shaft seals made by Freudenberg. So now gear oils from Klüber can be selected to ensure trouble-free operation. If the materials to be used are selected carefully, run-times of more than 20,000 hours can be attained.

General overview of the compatibility of gear oils with sealing materials

	Abbreviation	NBR	ACM	VQM	FKM	PTFE
	Type	Acrylonitrile butadiene rubber	Acrylate rubber	Silicone rubber	Fluorinated rubber, e.g. Viton	Polytetrafluoro-ethylen
	Thermal resistance	up to 100 °C	up to 125 °C	up to 125 °C	up to 150 °C	up to 150 °C
Klüberoil GEM 1 N	Mineral oil	•	•	□	■	■
Klübersynth GEM 4 N	Polyalpha-olefin	•	•	□	•	•
Klübersynth GH 6 Klübersynth UH1 6	Polyglycol	•	x	□	▪	•

• compatible ▪ compatible under certain conditions ■ Mineral oils are only compatible with seals up to 125 °C
□ Compatible with all gear oils, but air shedding may be impaired x not compatible

Wear protection

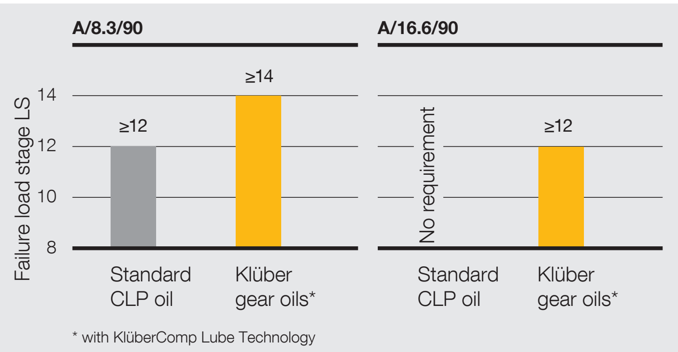
The challenging requirements in gear manufacture today include protection against seizure and micropitting, the reduction of wear under high sliding loads and the protection of rolling bearings against wear and fatigue.

Protection of gear teeth

Heavily loaded gears are potentially subject to seizure and pitting, as the high loads generate high pressures and temperatures, which in turn can lead to tooth damage resulting in premature gear failure. The risk is particularly high with less than perfect tooth contours and surfaces, impact loads, vibration, a high degree of sliding friction and high surface pressure.

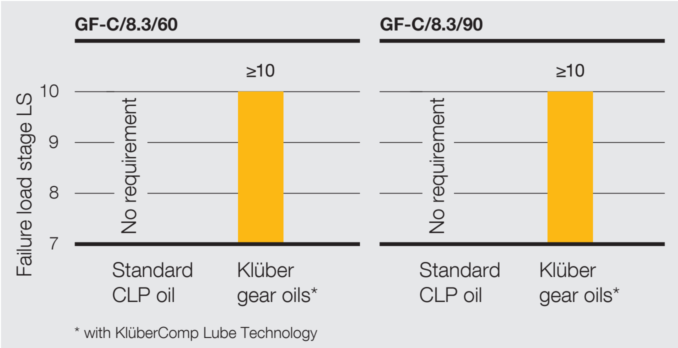
Scuffing: The FZG scuffing test according to ISO 14635-1 is generally undertaken to test the capability of gear oils to protect against scuffing damage. Load stage KS 12 of the FZG scuffing test is the minimum requirement for CLP oils according to DIN 51517-3 and EP oils according to AGMA 9005/E02.
Klüber Lubrication’s gear oils with KlüberComp Lube Technology surpass this level, offering superior protection with significantly higher scuffing load stages and speeds even under extreme shock load conditions.

FZG scuffing test (results)



Micropitting: The micropitting test according to FVA 54/7 has become the industry standard for assessing a gear oil’s micropitting load-carrying capacity as low, medium or high.
Klüber Lubrication’s gear oils with KlüberComp Lube Technology are classified as having high micropitting resistance, i.e. load stage ≥ KS 10.

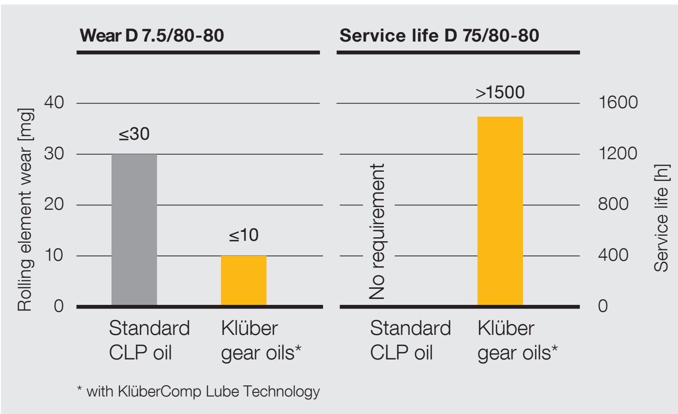
FZG micropitting test (results)



Protection of rolling bearings

Apart from the gear teeth, also the rolling bearings have to be protected against high wear and premature fatigue, which are often the reason for gearbox failures. The influence of high-performance gear oils on the wear behaviour of rolling bearings is examined in the FAG FE8 wear test according to DIN 51819-3. Klüber Lubrication’s gear oils surpass this test’s minimum requirements for CLP oils, while also attaining twice the calculated bearing life in the FE8 lifetime test. Consequently, these rolling bearings can attain the service life projected by the bearing design engineer.

FE8 rolling bearing test (results)



Conclusion:

The performance ratings stipulated by gear oil standards such as DIN 51517-3 or the similar AGMA 9005 are often not sufficient to ensure reliable operation. High-performance gear oils made by Klüber Lubrication surpass these standards and thus reliably protect gearboxes against tooth and bearing damage also in critical application situations.

Selection of the right gear oil

Mineral or synthetic gear oils

Today, many enclosed industrial gearboxes are still lubricated with mineral oils. Where these oils come up against their limitations, e.g. in terms of operating temperatures, the use of synthetic gear oils should be considered. Gear lubricants based on the following synthetic oils have proven most effective:

– polyalphaolefin (PAO)
– polyglycol (PG)
– ester (E)

Polyalphaolefins (PAO)

Polyalphaolefins have a chemical structure similar to mineral oils. They are therefore generally known under the designation synthetic hydrocarbons (SHC). Their compatibility with seal materials and paints is comparable to that of mineral oils. They should be disposed of or reprocessed in the same way as mineral oils and are miscible with mineral oil residues. Selected PAO base oils and corresponding additives may also be used for the manufacture of physiologically safe gear lubricants (H1 oils*) for use in the food-processing and pharmaceutical industries. Gear oils based on PAO show good oxidation resistance, enabling much longer oil change intervals. They also show especially good low-temperature behaviour.

Polyglycols (PG)

With polyglycol oils, very low friction results can be attained, which is why they are preferably used for the lubrication of gears with a high proportion of sliding friction, e.g. worm and hypoid gears. When combined with corresponding additives, they show excellent antiwear behaviour, especially in steel/bronze worm gears.

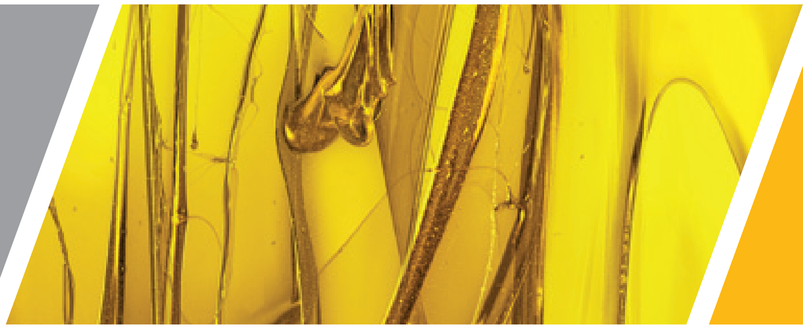
Just like gear oils based on PAO, oils based on specific polyglycols and additives may be used for the manufacture of physiologically safe gear lubricants (H1 oils*) for use in the food-processing and pharmaceutical industries.

Polyglycols are miscible with mineral oils to a limited extent only, so mixing should be avoided. Because of their high resistance to oxidation, polyglycols are often used at extremely high gear temperatures.

*) These lubricants are NSF H1 registered and therefore comply with FDA 21 CFR § 178.3570. The lubricants were developed for incidental contact with products and packaging materials in the food-processing, cosmetics, pharmaceutical or animal feed industries. The use of these lubricants can contribute to increase reliability of your production processes. We nevertheless recommend conducting an additional risk analysis, e.g. HACCP.

Comparison of the upper service temperature of a mineral oil with synthetic gear oils

Product	Oil type	ISO VG ISO 3448	Viscosity index ISO 2909	Upper service temperature (approx.)
Klüberoil GEM 1 N	Mineral oil	220	≥ 90	100 °C
Klübersynth GEM 4 N	Polyalphaolefin	220	≥ 150	140 °C
Klübersynth GH 6 Klübersynth UH1 6	Polyglycol	220	≥ 220	160 °C



Esters (E)

Synthetic ester oils are compounds of acids and alcohols. Innumerable different ester structures are therefore possible, each with different chemical and physical characteristics and giving rise to different lubricant properties. Depending on the individual type, ester oils may show particularly good thermal resistance or a particularly good low-temperature behaviour.

The ester oils used in industrial gears are normally of the rapidly biodegradable type. Their performance is generally comparable with that of polyalphaolefin or polyglycol oils.

Esters are miscible with mineral oils and polyalphaolefins. Mixing with polyglycols is possible to a limited extent only.

Benefits of synthetic gear oils

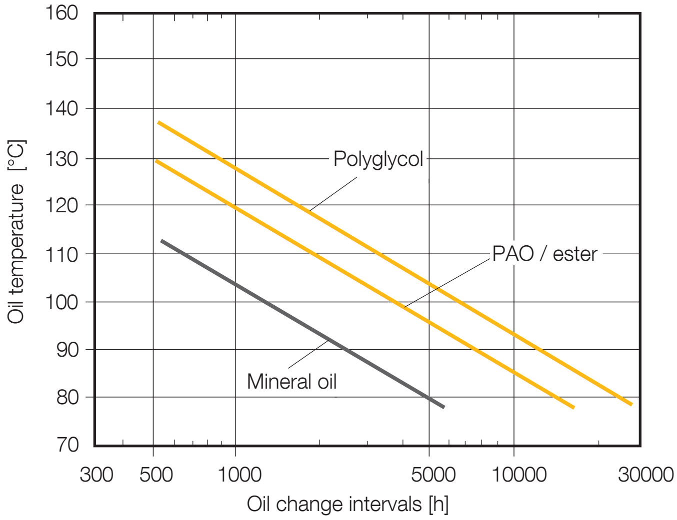
In addition to the wide service temperature range, synthetic gear oils offer many advantages compared to mineral oils:

- 3 to 5 times longer oil change intervals under the same thermal conditions
- Higher wear protection
- Better cold start with the same nominal viscosity (ISO VG)
- Oil coolers may not be required due to reduced operating temperatures under full load
- Lower gearing losses due to reduced friction leads to lower energy costs

Oil life time

The prolonged service life of synthetic lubricants and the consequent longer oil change intervals can reduce equipment downtime and save resources. In some cases, lubrication for-life is possible.

Typical oil change intervals



Selection of the right gear oil

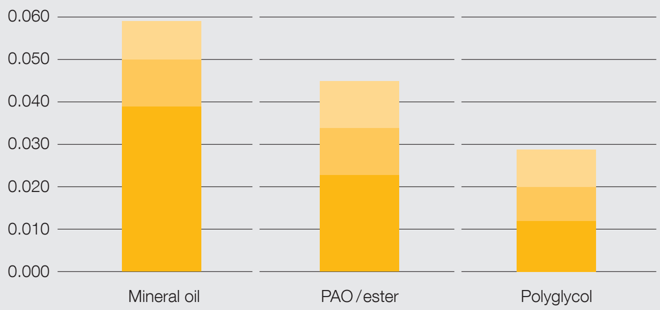
Improved efficiency by reducing gear friction losses

Synthetic gear oils based on polyalphaolefin, ester or polyglycol show a considerably lower gear friction coefficient than mineral oils due to their particular molecular structure.

The friction generated in gears with synthetic oils can be more than 30 % lower than that of an industrial EP mineral gear oil. Due to the lower friction coefficients of synthetic gear oils, they help reduce gearing losses considerably and hence increasing gear efficiency.

Especially in gearboxes with a high share of sliding friction, e.g. worm or hypoid gears, a changeover from mineral to synthetic gear oils can lead to increases in efficiency of more than 20 %.

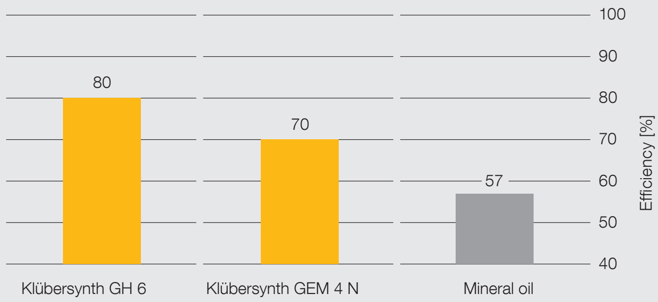
Friction coefficients of various gear oils determined on the twin-disk machine



v_Σ = 2 m/s
v_Σ = 4 m/s
v_Σ = 8 m/s

Hertzian pressure p_H	1000 N/mm²
Slip	20 %
Oil injection temperature	90 °C
ISO VG	150

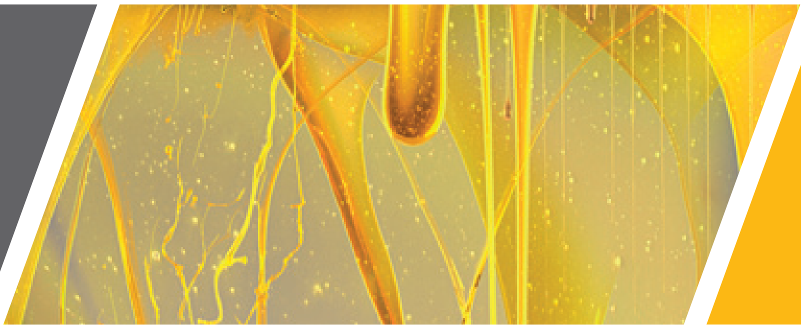
Efficiency determined on the Klüber worm gear test rig



Test gear:
Flender CUW 63
i = 1 : 39 ; a = 63 mm
Material worm 16MnCrS5
Material wheel GC - CuSn12Ni

Test conditions:

Input speed	350 1/min
Output torque	300 Nm
ISO VG 460	



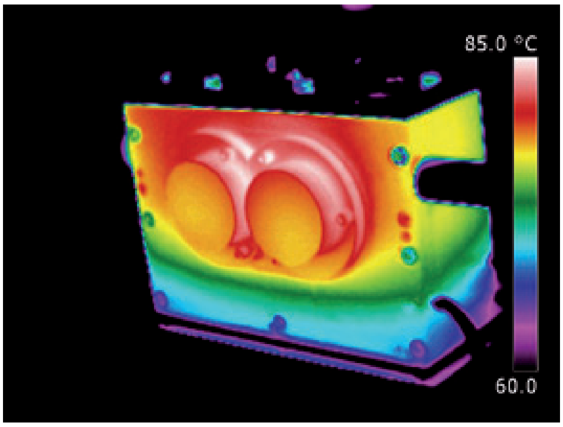
Even in spur and bevel gears that already operate with high efficiency, a changeover to synthetic gear oils may lead to a further efficiency increase of up to 1 %. While this might not sound like much at first, it may lead to substantial energy cost savings depending on the power rating of a gearbox or the total number of gearboxes used. The various degrees of efficiency improvement that can be attained by synthetic gear oils, especially in gears where gearing losses due to higher loads are high, are shown in the following table.

Gear type ▶	**Worm gears, hypoid gears**	**Spur or bevel gears, axes not offset**
Effect ▼		
Reduction of total loss	30% or more	20% or more
Efficiency improvement	20% or more	up to 1%
Reduction of operating temp. (steady-state temperature)	20 °C or more	5 °C or more

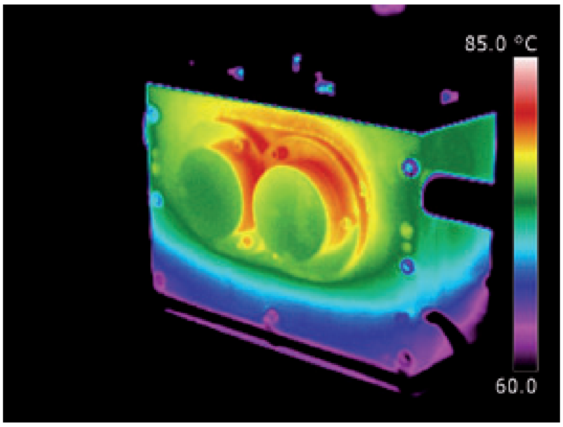
Potential reduction of gearing losses and improvement of efficiency by using a synthetic oil instead of a mineral oil

The synthetic gear oils made by Klüber Lubrication offer significantly higher efficiency than a standard gear oil based on mineral oil, resulting in a lower oil temperature as shown in the thermal pictures.

Standard gear oil
(Mineral oil, ISO VG 220)



Klübersynth GEM 4-220 N
Klüberoil 4 UH1-220 N



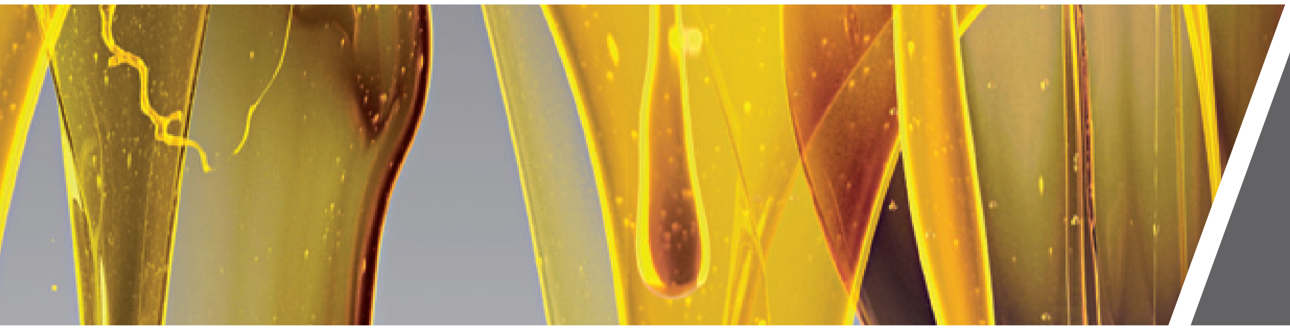
Even in spur gears, an oil temperature reduction from 85 °C with mineral oil to 80 °C with Klüber's synthetic gear oils based on PAO can be achieved. This results in a reduction of energy consumption, longer lifetime of the gearbox and less maintenance.

Overview of Klüber gear oils

Klüber gear oils	Base oil	Available ISO VG	Gear type			Service temperature range	
			Spur, bevel, planetary gears	Hypoid gears	Worm gears	Lower service temperature (approx.)	Upper service temperature (approx.)
Klüberoil GEM 1 N*	MIN	46…1000	+++	++	+	–15 °C	100 °C
Klübersynth GEM 4 N*	PAO	32…680	+++	+	++	–50 °C	140 °C
Klübersynth GH 6*	PG	22…1500	++	+++	+++	–55 °C	160 °C
Klübersynth UH1 6*/**	PG	100…1000	++	+	+++	–35 °C	160 °C
Klüberoil 4 UH1 N**	PAO	32…1500	++	+	+	–35 °C	120°C
Klübersynth GEM 2	Ester	220, 320	++	+	+	–30 °C	130 °C
Klübersynth G 4	PAO	68…220	++	+	+	–40 °C	140 °C
Klübersynth EG 4	PAO	150…1000	++	++	+	–35 °C	140 °C
Klübersynth GHE 6	PG	100, 460	+++	++	+	–35 °C	160 °C
Klübersynth GE 4 75 W 90	PAO	–***	++	+++	+	–40 °C	150 °C
Klüberbio CA 2	Ester	100, 460	++	+	+	–30 °C	110 °C
Klüberbio EG 2	Ester	150	++	+	+	–25 °C	100 °C
Standard CLP-Öl	–	–	–	–	–	No requirement	No requirement

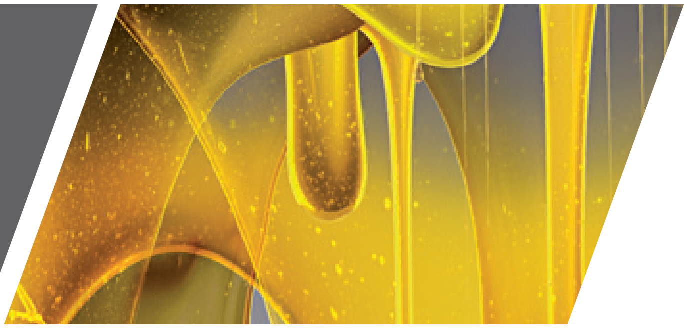
+++ Optimum performance /benefit ++ Increased performance / benefit + Standard

* KlüberComp Lube Technology ** H1 certified *** SAE viscosity class 75 W 90



	Performance parameters				DIN 51517-3, AGMA 9005 denomination	Possible energy saving
	Oil life	Protection of gear teeth (against seizure, micropitting, pitting)	Protection of rolling bearings (against wear, pitting)	Compatibility with radial shaft seal elastomers		
	+	+++	+++	+++	CLP, EP oil	+
	++	+++	+++	+++	CLP, EP oil	++
	+++	+++	+++	+++	CLP, EP oil	+++
	+++	+++	+++	+++	CLP, EP oil	+++
	++	++	+++	++	CLP, EP oil	++
	++	+++	+++	+	-	++
	++	+	+	+	-	++
	++	+	+	+	EP oil	++
	+++	++	++	++	CLP, EP oil	+++
	++	++	++	+	-	++
	++	+	++	+	CLP, EP oil	++
	++	++	++	+(+)	CLP, EP oil	++
	–	Minimum requirement	Minimum requirement	Minimum requirement	CLP, EP oil	No requirement

Viscosity selection



The required gear oil viscosity depends on the gear geometry and loads. It can be determined on the basis of DIN 51509-1 by calculating the force-speed factor ks/v for each gear stage. In addition to the gear dimensions, this factor also takes into account other parameters influencing the viscosity like the gear speeds and loads. For the calculation of the force-speed factor, one has to distinguish between the following types of gears:

Spur gears, bevel gears

$$\frac{k_S}{v} = \left[\frac{F_t}{b \cdot d_1} \cdot \frac{u+1}{u} \cdot Z_H^2 \cdot Z_\varepsilon^2 \cdot K_A\right] \Big/ v$$

v	Peripheral speed	[m/s]
F_t	Peripheral force	[N]
b	Tooth width	[mm]
d_1	Reference diameter	[mm]
u	Gear ratio (= z_2/z_1; $z_2 > z_1$)	[–]
K_A	Application factor	[–]
Z_H	Distribution factor	[–]
Z_ε	Contact ratio	[–]

Worm gears

$$\frac{k_S}{v} = \frac{T_2}{a^3 \cdot n_s} \cdot K_A$$

T_2	Output torque	[Nm]
a	Shaft centre distance	[m]
n_S	Worm speed	[min⁻¹]
K_A	Application factor	[–]

Additional formulae:

$F_t = 2000 \cdot T_1 / d_1$
(input torque T_1 in [Nm],
reference diameter d_1 in [mm])

$v = \pi \cdot d_1 \cdot n_1 / 60000$
(reference diameter d_1 in [mm],
torque n_1 in [min^{-1}])

Approximation: $Z_H^2 \cdot Z_\varepsilon^2 = 3$
Note: Guide values for K_A
are listed in DIN 3990-6.

Determination of application factor K_A				
Operating characteristics of driving machine	**Operating characteristics of driven machine**			
	uniform	**moderate shocks**	**medium shocks**	**heavy shocks**
uniform	1	1.25	1.5	1.75
light shocks	1.1	1.35	1.6	1.85
moderate shocks	1.25	1.5	1.75	2
heavy shocks	1.5	1.75	2	2.25 or higher

The values apply to the nominal torque of the driven machine, alternatively to the nominal torque of the driving motor, if it corresponds to the torque demand of the driven machine. The values stated are only valid for machines not operating in the resonance range and only if they have a uniform power requirement. In applications with acceptable loads, motors with high starting torque, intermittent operation, extreme and recurring shock loads, the gears should be checked for static and fatigue strength. For examples, see DIN 3990, part 6, page 9.

Examples of driving machines with different operating characteristics

Characteristic	Driving machine
uniform	Electric motor (e.g. DC motor), steam/gas turbine in steady operation *) (low starting torques at long intervals) **)
light shocks	Steam turbine, gas turbine, hydraulic/electric motor (higher starting torques at short intervals) **)
moderate shocks	Multi-cylinder internal combustion engine
heavy shocks	Single-cylinder internal combustion engine

*) As determined in vibration tests or empirically with similar systems
**) see service life curves ZNT; YNT of the material in DIN 3990 part 2 and part 3. Consideration of short-term overload torques

Examples of operating characteristics of the driven machine

Characteristic	Driven machine
uniform	Power generators; continuously fed belt and apron conveyors; feed screws; light elevators; packaging machines; machine tool feed drives; fans; light centrifuges; rotary pumps; agitators and mixers for light fluids or substances of even density; shears; presses; punches[1)]; rotary units; travel gears[2)]
moderate shocks	Intermittently fed belt and apron conveyors; machine tool main drives; heavy elevators; rotary units of cranes; industrial and mining fans; heavy centrifuges; rotary pumps; agitators and mixers for viscous fluids or substances of varying density; multi-cylinder piston pumps; feeding pumps; extruders in general; calenders; rotary kilns; rolling mills[3)] (continuous zinc band, aluminium belt mills, wire and rod mills)
medium shocks	Rubber extruders; intermittently operating mixers for rubber and synthetic materials; light-weight ball mills; woodworking machines (gate saws, turning lathes); blooming mills [3),4)]; hoisting units; single-cylinder piston pumps
heavy shocks	Excavators, bucket wheel chain drives; screen drives; shovel dredgers; heavy ball mills; rubber kneaders; stone and ore crushers; mining machinery; heavy feed pumps; rotary drilling installations; brick presses; debarking drums; peeling machines; cold belt mills[3),5)]; briquetting presses; pan grinders

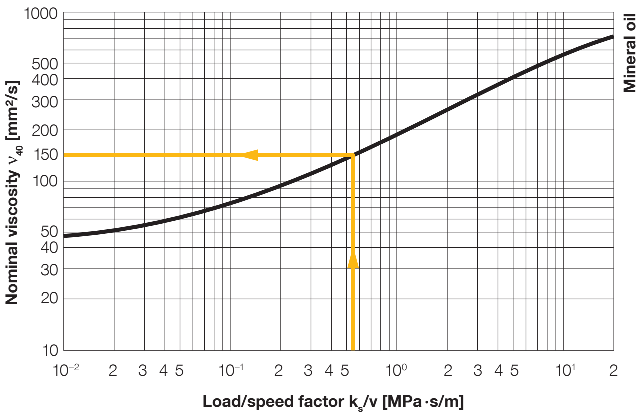
1) Nominal torque = maximum cutting, pressing, punching torque 2) Nominal torque = maximum starting torque 3) Nominal torque = maximum rolling torque
4) Torque based on power limit 5) K up to 2.0 due to frequent belt breakage

Viscosity selection

Mineral oils

After having determined the critical force-speed factor k_s/v, the required nominal viscosity for mineral oils can be plotted acc. to DIN 51509-1. Distinction is made between the different gear types.

Viscosity selection for spur gears, bevel gears



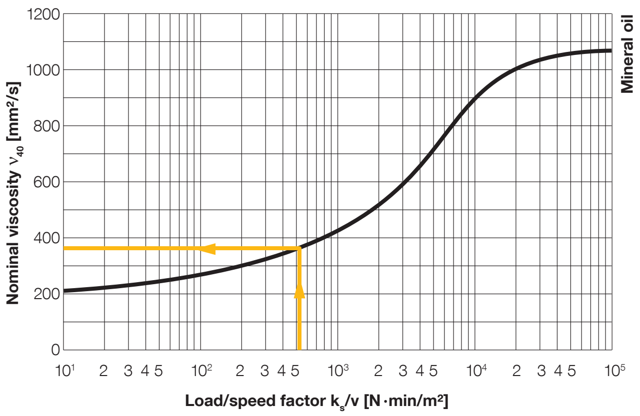
Note:

The curves of mineral oil viscosity shown apply to an ambient temperature of 20 °C and an operational oil temperature of 70 °C.

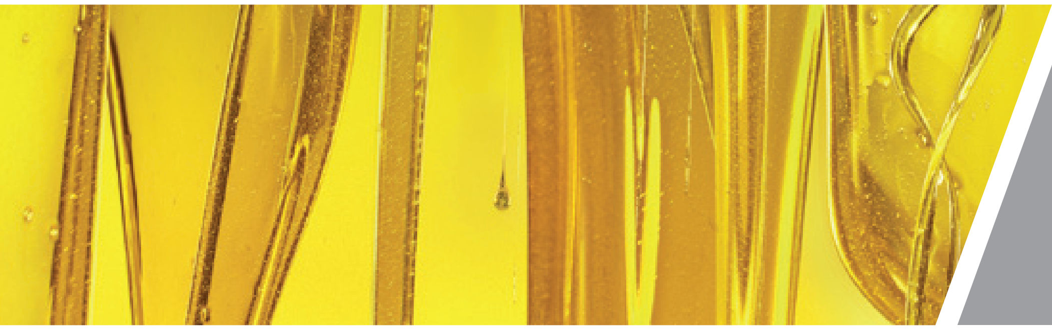
If the ambient temperature is permanently above 25 °C, the viscosity has to be increased by approx. 10 % for every 10 °C temperature rise versus the ambient temperature of 20 °C.

If the ambient temperature is permanently below 10 °C, the viscosity has to be decreased by approx. 10 % for every 3 °C temperature drop versus the ambient temperature of 20 °C.

Viscosity selection for worm gears



For the loads of two-stage gears, the gear stage with the higher force-speed factor k_s/v is the one to be considered. For three-stage gears, one has to interpolate between the two most critical gear stages.



Synthetic gear oils

The required nominal viscosity for Klüber synthetic gear oils can be determined by means of the Klüber Viscosity Index KVZ and the expected operating temperature of the oil. For this purpose the force-speed factor k_s/v is calculated for each gear stage and used for determining the Klüber viscosity index KVZ.
Again, distinction is made between the different gear types.

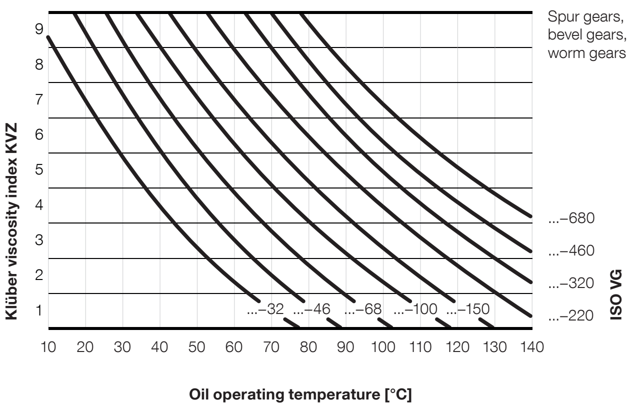
After having determined the Klüber viscosity index KVZ, the required nominal viscosity for Klüber synthetic gear oils, which are available in many ISO VG grades, can be selected from the diagrams starting on page 22 taking into account the expected operating temperature of the oil.
Note: The operational oil temperature is the oil sump temperature or the temperature of the injected oil.

Spur gears, bevel gears		
$k_s/v \left[\frac{MPa \cdot s}{m}\right]$	KVZ	
≤ 0.02	1	
> 0.02 to 0.08	2	
> 0.08 to 0.3	3	
> 0.3 to 0.8	4	Example 1
> 0.8 to 1.8	5	
> 1.8 to 3.5	6	
> 3.5 to 7.0	7	
> 7.0	8	

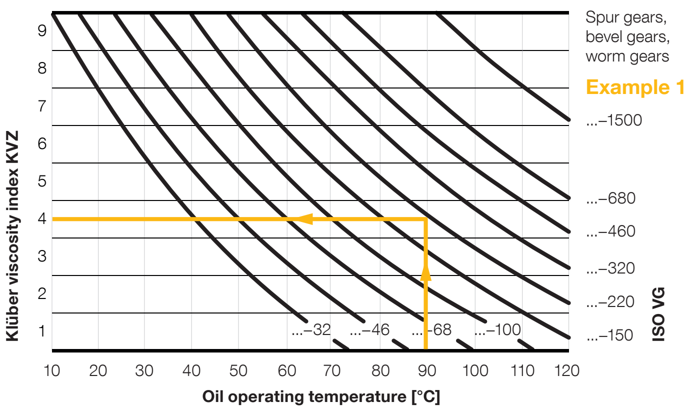
Worm gears		
$k_s/v \left[\frac{MPa \cdot s}{m}\right]$	KVZ	
≤ 60	5	
≤ 60	6	
> 400 to 1800	7	
> 1800 to 6000	8	Example 2
> 6000	9	

Viscosity selection

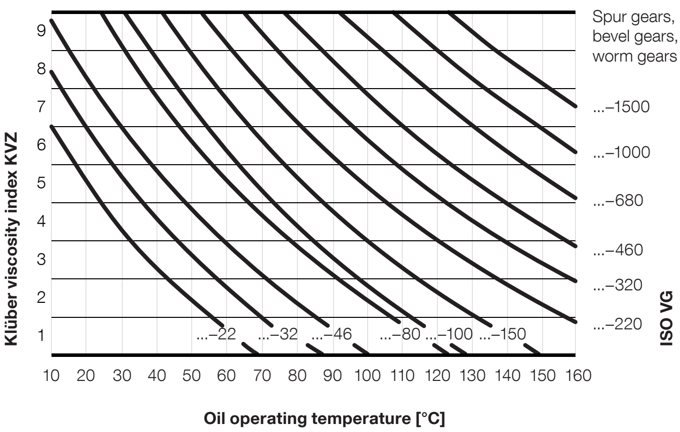
Viscosity selection (ISO VG) for Klübersynth GEM 4 N



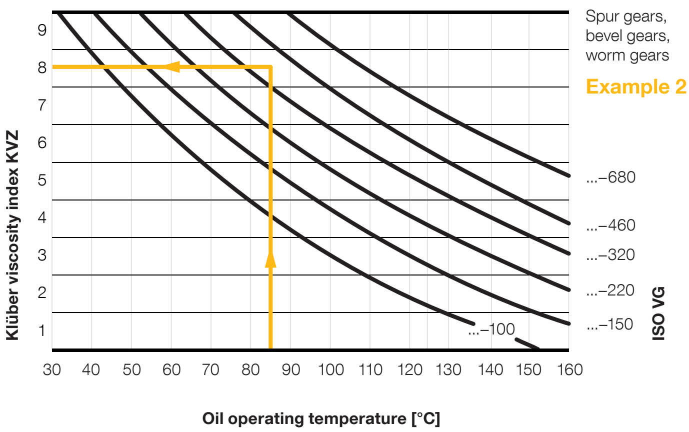
Viscosity selection for Klüberoil 4 UH1 N



Viscosity selection for Klübersynth GH 6

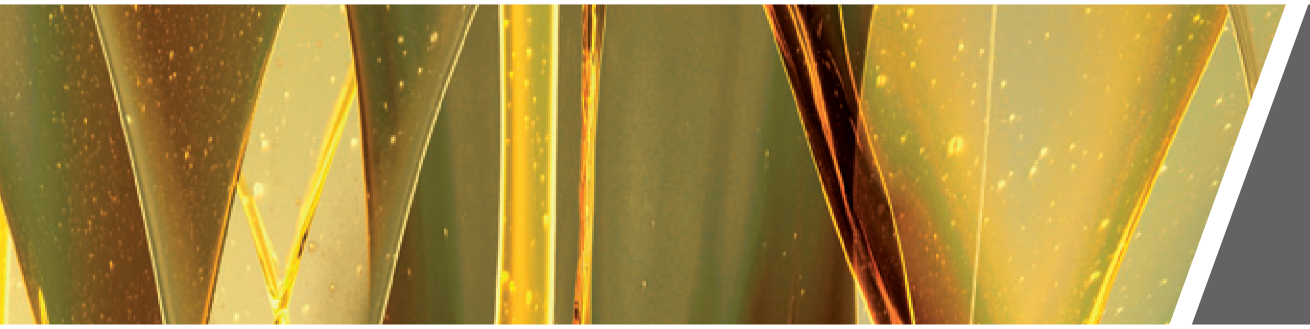


Viscosity selection for Klübersynth UH1 6



Hint: In case of doubt always select the next higher viscosity grade. At low temperatures it is important to take into account the gear oil's flow limit!

Hint: After having determined the required viscosity grade, we also recommend considering the scuffing resistance. In addition, it is important to take into account the viscosity requirements of the other lubrication points in the gearbox, i.e. rolling bearings, plain bearings, couplings, oil pumps, etc.



Example 1:

Single-stage spur gear for driving a fan
in the beverage industry

Drive:	Electric motor
Nominal tangential load:	$F_t = 3000$ N
Tooth width:	b = 25 mm
Reference diameter:	$d_1 = 230$ mm
Gear ratio:	u = 2.5
$Z_H^2 \cdot Z_\varepsilon^2$:	≈ 3
Application factor:	$K_A = 1$
Circumferential speed:	v = 4 m/s
Stribeckian contact pressure:	$k_S = 2.2$ MPa
Force-speed factor:	$k_S/v = 0.55 \frac{\text{MPa} \cdot \text{s}}{\text{m}}$
Klüber viscosity number from table on p. 21:	KVZ = 4
Oil sump temperature to be expected:	≈ 90 °C

Selected gear oil certified as H1:
Küberoil 4 UH1-220 N with ISO VG 220

Example 2:

Worm gear stage of a gear motor driving a
circular conveyor in the beverage industry

Drive:	Electric motor
Output torque:	$T_2 = 300$ Nm
Worm speed:	$n_1 = 350\ \text{min}^{-1}$
Shaft centre distance:	a = 0.063 m
Application factor:	$K_A = 1$
Force-speed factor:	$k_S/v = 3428 \frac{\text{N} \cdot \text{min}}{\text{m}^2}$
Klüber viscosity number from table on p. 21:	KVZ = 8
Oil sump temperature to be expected:	≈ 85 °C

Selected gear oil certified as H1:
Kübersynth UH1 6-460 with ISO VG 460

Oil level, immersion depth and oil quantities

Most enclosed industrial gears are lubricated by oil. The simplest way of supplying lubricant to the components is by immersion. This method combines the benefits of being economical and simple with reliable, continuous lubrication and a cooling effect that is sufficient for many applications. Splashing oil may also wet gears and rolling bearings that are not themselves immersed in the oil bath.

This splashing effect can be enhanced by fitting additional splashing disks on the gear shafts. Immersion oil lubrication works well without specifically adjusted gear design up to peripheral speeds of approx. 20 m/s. If plates and pockets are fitted to guide the oil movement, higher peripheral speeds are also possible.

With splash lubrication it is important that a certain oil level is maintained at all times in order to ensure damage-free operation. If the oil level is too low, it may result in starved lubrication, inadequate heat dissipation and increased wear. If the oil level is too high, churning losses may increase, resulting in higher oil temperatures and gear friction losses. In order to keep churning losses low, the depth of immersion is reduced with increasing peripheral speed.

Recommended immersion depth		
Type of gears	**Operating conditions**	**Immersion depth**
Spur gears	Peripheral speed up to 5 m/s	3 to 5 times the module size
	Peripheral speed > 5…20 m/s	1 to 3 times the module size
Bevel gears	–	Teeth immersed across the whole wheel width
Worm gears	Worm over wheel	Wheel immersed to approx. 1/3 of its diameter
	Wheel over worm	Wheel immersed approx. halfway the mesh
	Lateral worm	Wheel immersed at least halfway the worm height

Further oil lubrication methods are immersion circulation lubrication and force-feed lubrication. In applications where peripheral speeds are too high for immersion lubrication, and for most gears running in plain bearings, force feed lubrication injecting oil directly to the mesh is used.

Recommended lubrication methods		
Gears	**Peripheral speed**	**Lubrication methods**
Spur and bevel gears	up to 20 m/s from 20 to 250 m/s	Immersion lubrication Oil injection lubrication
Worm gears (worm immersion)	up to 12 m/s from 12 m/s	Immersion lubrication Oil injection lubrication
Worm gears (wheel immersion)	up to 8 m/s from 8 m/s	Immersion lubrication Oil injection lubrication

Force-feed lubrication is suitable for even the highest peripheral speeds encountered in gear systems. Oil is brought onto the tooth flanks via slotted or perforated nozzles. The injection quantity depends on the amount of heat to be dissipated.
As a rule of thumb we recommend:

0.5 to 1.0 l/min per cm of tooth width

Hint: The required oil circulation quantity is made up of the lubricant quantity required for the gear wheels plus the quantity required for the bearings.

Oil change: How it's done

Normal oil change without changeover

Oil-lubricated gears require an oil change from time to time since the oil changes its characteristics beyond limits due to the working and ambient conditions, e.g. ageing, abrasion and contamination. The objective of the oil change is to ensure continued reliable lubrication. This is also the objective when replacing a gear oil that is basically still fit for use, but not under the prevailing operating conditions.

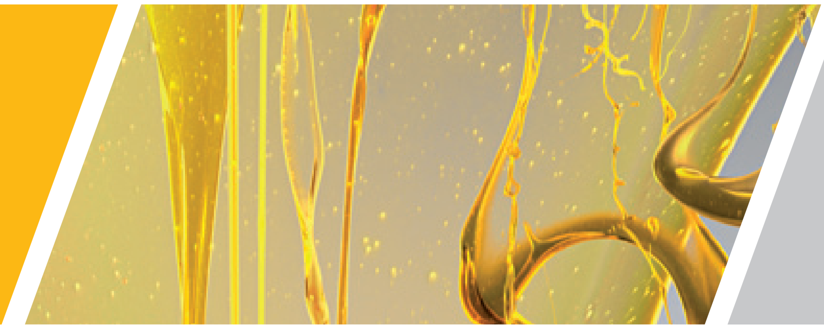
When an oil change of this type is performed, some residual oil will always remain in the gearbox. In many cases, these residues cannot be tolerated and must be removed. The simplest method is flushing the gears. If possible, the old gear oil is drained while still warm, i.e. immediately after the gears are stopped. Draining is followed by flushing to remove residues. The oil container and inside walls of the gearbox can also be cleaned by non-fraying cloth – do not use cleaning wool – and/or a rubber blade.

A bigger problem is more profound contamination in the form of deposits caused by strongly aged oil. In such cases it is inevitable that the gears be cleaned by means of cleaning oil and manual cleaning, as far as accessible. A suitable oil for cleaning gears is KlüberSummit Varnasolv, which quickly dissolves residues when added to mineral oil or PAO at a concentration of 10 %, i.e. by draining approx. 10 % of the gear oil, and then topping up with KlüberSummit Varnasolv. After 24 to 48 hours of operation, the oil can be drained. Any remaining residues can be removed mechanically.

Oil change checklist – Gear inspection

Clean gears

1. Drain oil while warm
2. Inspect teeth
3. Replace filters
4. Fill in new oil
5. Put gear into operation and stop again
6. Check oil level
7. Take reference oil sample, if required



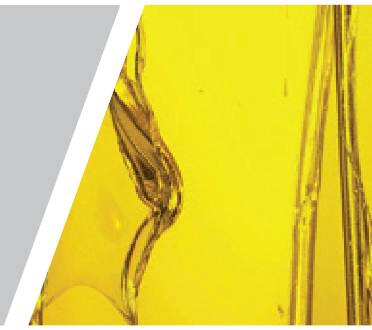
Contaminated gears

- Drain oil while warm
- Fill flushing oil
- Operate gear for approx. 30 to 60 min without load or injection system only
- Drain flushing oil
- Inspect teeth
- Replace filters
- Fill in new oil
- Put gear into operation and stop again
- Check oil level
- Take reference oil sample, if required

Strongly contaminated gears

- Drain approx. 10 % of the oil fill while warm
- Top up with Varnasolv
- Operate gears for 24 - 48 hours
- Drain oil while warm
- Fill flushing oil*
- Operate gear for approx. 30 to 60 min without load or injection system only*
- Drain flushing oil*
- Inspect teeth
- Replace filters
- Fill in new oil
- Put gear into operation and stop again
- Check oil level
- Take reference oil sample, if required

* if required



Oil change: How it's done

Changeover from mineral to synthetic gear oil

Which synthetic gear oil is best suited for a changeover should not be decided by the end user alone, but always be agreed together with the gear and/or equipment manufacturer.

Every changeover from mineral to synthetic oil should be performed with great care. It may not be enough to simply drain the used mineral oil and fill in the new synthetic oil. Older gears, in particular, can be assumed to contain oil residues in the casing, the oil lines etc., which might be dissolved by synthetic oils. If such residues are not removed, they may cause problems during operation. Oil lines and filters may be clogged, seals, pumps and teeth damaged. By replacing approx. 10 % of the existing mineral oil fill with Klüber Summit Varnasolv, oil residues can be dissolved to make cleaning of the gear easier. To prevent damage, the gear or lubricant circulation system should be flushed with the new synthetic oil after the old oil has been drained, ideally at operating temperature.

Flushing should be repeated once or twice when changing over to H1-registered or bio-lubricants like Klüber oil 4 UH1 N or Klüberbio oils to ensure that all mineral oil residues are removed and important features like food safety or rapid biodegradability are not impaired.

The synthetic gear oil that was used for flushing must not be used for lubrication afterwards, however, it can be kept for further flushing operations. Prior to filling the fresh synthetic oil, oil filters or filter elements should be replaced.

Changeover from mineral oil for polyalphaolefin (PAO)

– Klübersynth GEM 4 N
– Klüberoil 4 UH1 N
– Klübersynth GE 4 75 W 90
– Klübersynth G 4

Polyalphaolefins have a chemical structure similar to that of mineral oils. Therefore, they can be mixed with residual mineral oil which cannot be removed by normal oil draining. However, in order to maintain the oil's full performance, residual mineral oil content in the gearbox, circulation system and oil containers should not exceed 5 %.

Synthetic oils with a base oil other than PAO must not be mixed, whereas gear oils based on PAO from different manufacturers are miscible, however their content should be kept as low as possible in order not to affect the properties of the original gear oil.

At operational oil temperatures over 80 °C, it is recommended to use only seals made from fluorinated rubber or polytetrafluoroethylene (PTFE). At temperatures below 80 °C, seals made from NBR are also resistant to PAO oils.

For the inside coating of gearboxes we recommend using epoxy and polyurea paints.

Changeover from mineral oil to polyglycol (PG)

– Klübersynth GH 6
– Klübersynth UH1 6
– Klübersynth GHE 6

Polyglycols are miscible neither with mineral oils nor other synthetic gear oils. Polyglycols from different manufacturers are miscible, however their content should be kept as low as possible in order not to affect the properties of the original gear oil.

When using polyglycol oils, make sure you know the materials of your seals, paints and inspection glasses to rule out undesirable interaction with the lubricant. At operational oil temperatures over 80 °C, it is recommended to use seals made from fluorinated rubber or polytetrafluoroethylene (PTFE) only. Below 80 °C, seals made of NBR are also resistant to PG oils.

Epoxy and polyurea paints are recommended for internal coating of housings. Polyglycols are neutral towards ferrous and nearly all non-ferrous metals. Where one or both friction bodies consist of an aluminium alloy, however, e.g. rolling bearing cages or worm wheels containing aluminium, a combination of dynamic loads, high sliding speeds and high loads may lead to increased wear, however only occasionally. Compatibility tests are therefore recommended for applications where this is the case.

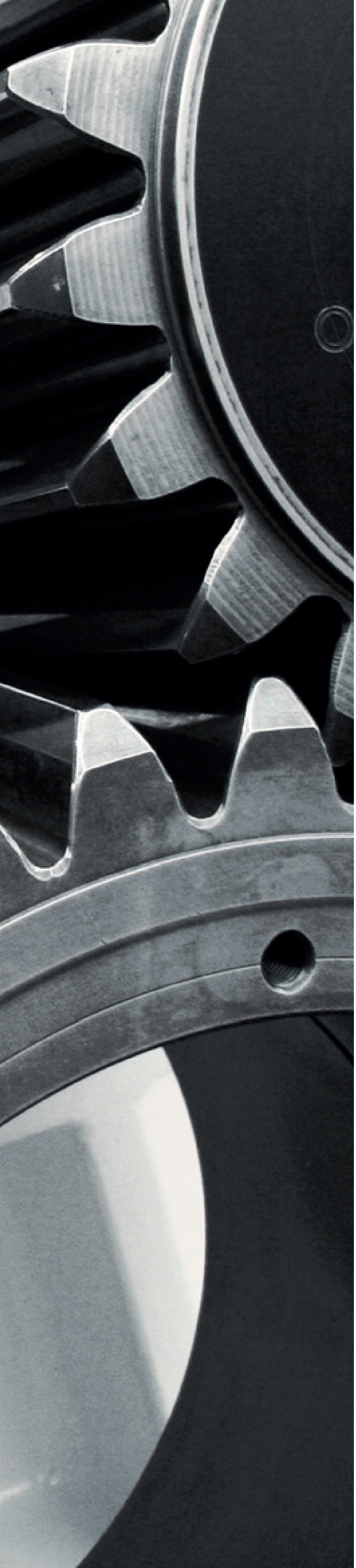
For function testing, running-in and long-time storage of gears intended for future lubrication with polyglycol oils, Klübersynth GEZ 6-220 may be used.

Changeover from mineral oil to ester (E)

- Klübersynth GEM 2
- Klüberbio EG 2
- Klüberbio CA 2

When changing over to ester gear oils, make sure you know the materials your seals, paints and inspection glasses are made of to rule out undesirable interaction with the lubricant.

Esters are miscible with mineral oils and polyalphaolefins. Mixing with polyglycols is possible to a limited extent only. Mixing with esters from other manufacturers is permissible as long as they are of the same ester type. The content of other oils should be kept as low as possible in order not to affect the properties of the original gear oil.



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