

# How polyglycol-based oils perform in lubricating large enclosed gear drives

- In modern-day gear technology, the lube oil used is an important element for the gear's overall design. Increasingly stringent requirements for large enclosed gear drives, of the kind used in the wind power sector, for example, and the base materials industry, nowadays necessitate the use of synthetic oils.
- Although the feedback is positive regarding the use of synthetic gear oils based on polyglycol, there continues to be a residual uncertainty concerning their usability in terms of elastomer seals and a possible performance restriction due to their water-solubility. The favorable friction behavior of polyglycols has meant that these oils have become widely adopted for lubricating worm gears. This paper intends to show that polyglycols also constitute a fully viable solution for use in large gears, which may even be more advantageous than using the polyalphaolefins.

## The oils tested

For the tests described below, one mineral oil and two different polyglycol gear oils, whose properties are explained in Table 1, were selected.

	ISO VG	Viscosity Index	Basis	Features
<b>M 320</b>	320	95	Min	High additive content CLP FZG A/16,6/90 >13
<b>PG 320 - 1</b>	320	> 230	PG	High additive content CLP FZG A/16,6/90 >13
<b>PG 320 - 2</b>	320	> 220	PG	Additive package approved for the <b>food industry</b> CLP FZG A/8,3/90 >12

Table 1: The oils tested

Whereas the properties of mineral oil are known, and the behavior of polyalphaolefins in the ranges of relevance for gear construction is comparable to that of mineral oils, polyglycols exhibit properties which differentiate them from mineral oils and polyalphaolefins.

## Polyglycols

The basic raw material used for producing the various synthetic lubricants, which include the polyalphaolefins and polyglycols, is ethylene, which is obtained by cracking crude oil. The polyalphaolefins are produced by polymerization of the olefin 1-decen, which in turn is created by oligomerization of ethylene. Chain length, branching and positions of the branches in the molecule determine the viscosity, viscosity-temperature behavior and the pour point of the liquid.

When ethylene and propylene react with oxygen, we obtain ethylene oxide (EO) and propylene oxide (PO), from which the polyalkylene glycols are produced by means of polymerization.

The mixing ratio between EO and PO, plus the oxygen bonded in the chemical structure, crucially affect the behavior of polyglycols. Since the gear industry predominantly uses polyglycols with an EO/PO ratio of 50:50 to 60:40, which exhibit very similar behavior, only these types will be dealt with here. The polyglycols featuring this composition are also generally referred to as water-soluble polyglycols.

The principal cause of the distinctive behavior of polyglycols, however, is the bonded oxygen, which lends the polyglycols their particularly polar character.

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## Behavior with water

By reason of their structure, polyglycols absorb a greater or lesser amount of water. Firstly, this behavior is dependent on the ratio of ethylene glycol to propylene glycol, and secondly, a distinction also has to be drawn between absorption due to admixture of water, water-solubility and absorption due to atmospheric moisture, hygroscopicity.

## Water-solubility

The water-solubility of polyglycols is determined by their content of ethylene oxide groups. Whereas pure propylene glycols, EO/PO 0:1, are not water-soluble, but can certainly absorb up to 3% of water, polyglycols can be unrestrictedly mixed with water as from an EO/PO mixing ratio of 1:1.

This miscibility is limited only by the temperature. At a higher temperature, the solubility decreases in dependence on the EO/PO ratio. In the case of polyglycols with an EO:PO ratio of 1:1, this temperature lies at 60 to 65°C.

## Hygroscopicity

Polyglycols' characteristic of forming a hydrate envelope is so marked that polyglycols absorb moisture from the air, are hygroscopic. This hygroscopicity, too, is influenced significantly by the type of polyglycol involved.

While pure polypropylene glycols can absorb max. 3% of water, the figure for 1:1 types is up to 10%, at ambient temperature and a relative humidity of 80%.

However, absorption from the air is substantially influenced by the relative humidity, the temperature, the surface and the time involved. The above-mentioned balancing concentration is unlikely to be reached in enclosed gears, since the oil surface is very small in relation to the oil volume. In addition, the standstill times are often very short, so that the amount of exchange occurring is small.

By reason of this property, polyglycols are accordingly supplied with water contents of 500 to 2000 ppm.

## Seal resistance

The seal materials customarily used in gears are elastomers based on NBR and FKM. While the use of NBR elastomer seals in combination with mineral oil and polyalphaolefins is regarded as non-critical, the use of polyglycols always raises the question of compatibility with the elastomer being used.

The static tests conducted in the past for assessing the seal-compatibility of various elastomers with the operating liquids used are progressively being replaced in the gear construction sector by testing under dynamic conditions.

The test is run for a duration of 1000 hours at a test temperature of 80°C for mineral products and 110°C for synthetic products. Usually, the influence on NBR and FKM is examined. Assessment criteria for resistance are:

- leak integrity
- carbon build-up
- abrasion at the sealing lip
- bubble formation
- wear in the shaft

The tests conducted under the above-mentioned conditions show that the polyglycol gear oils involved have no adverse effect either on the NBR qualities used or on the FKM seals employed in terms of their sealing properties (Fig. 1).

## NBR & FKM seal compatibility—dynamic test results

Produktentwicklung Industrie				
<b>Versuchsansatz: Versuche</b> Einbauteile: Industriegetriebe	<b>Prüfprogramm</b> A: 24h * 42 80 °C B: 24h * 42 110 °C	1500 U/min 1500 U/min	<b>RWDR-Bezeichnung: BAU ... 35-52-7</b> Werkstoff A: 72 NBR 902 Werkstoff B: 75FPM585 Randnummer: Laufzeit: 1000 h	
<b>RWDR-Bezeichnung:</b> Öl- (Additiv-) - Hersteller Ölbezeichnung Versuchs-Nr. CF Werkstoff	BAU32 35-52-7 Klüber M 320 54742 A 54743 A	BAUMX 35-52-7 Klüber M 320 54744 B 54745 B	BAU32 35-52-7 Klüber PG 320 - 2 54738 A 54739 A	BAUMX 35-52-7 Klüber PG 320 - 2 54740 B 54741 B
<b>Diehtfunktion</b> Leckage (ml) Dichtzeit (%) Dichtzeit (h)	--- 100 100 1000 1000	--- 100 100 1000 1000	--- 100 100 1000 1000	--- 100 100 1000 1000
<b>Laufparameter: (mm)</b> Optische Befragung Dichtlippe	0,25-0,3 0,2-0,28	0,2-0,25 0,2-0,25	0,15-0,25 0,25	0,28-0,72 0,25-0,6
Laufsaur-Verfärbung Ölkohlebildung Verschmierung Rißbildung Blasenbildung Rölle in Laufsaur Bemerkung Befragung Test-Welle Ablagerungen Einlaufzeit	+++ ++ +++ ++ +++ ++ +++ ++ +++ ++ +++ ++ +++ ++ --- --- --- ---	+++ ++ +++ ++ +++ ++ +++ ++ +++ ++ +++ ++ +++ ++ --- --- --- ---	+++ ++ +++ ++ +++ ++ +++ ++ +++ ++ +++ ++ +++ ++ --- --- --- ---	+++ ++ +++ ++ +++ ++ +++ ++ +++ ++ +++ ++ +++ ++ 13,2 9,6 --- ---
<b>Allgemeine Bemerkungen</b>	Unter oben genannten Bedingungen ist kein signifikanter Negativverfluss des Mediums auf die Dichtwirkung zu erkennen	Unter oben genannten Bedingungen ist kein signifikanter Negativverfluss des Mediums auf die Dichtwirkung zu erkennen	Unter oben genannten Bedingungen ist kein signifikanter Negativverfluss des Mediums auf die Dichtwirkung zu erkennen	(Sichtverursacht) in Verbindung mit Rißbildung und Wellenrölle
<b>Legende</b> <b>o</b> <b>b</b> <b>a</b> <b>c</b> <b>+</b> <b>+</b> <b>+</b> <b>g</b> <b>e</b> <b>n</b> <b>i</b> <b>g</b> <b>+</b> <b>+</b> <b>d</b> <b>e</b> <b>a</b> <b>r</b> <b>i</b> <b>c</b> <b>h</b> <b>+</b> <b>s</b> <b>t</b> <b>r</b> <b>k</b> <b>-</b> <b>s</b> <b>c</b> <b>h</b> <b>r</b> <b>s</b> <b>t</b> <b>r</b> <b>k</b> <b>-</b> <b>-</b>				

Fig. 1: Results for dynamic seal-compatibility

## Properties of polyglycols—the influence of water

For gear oils which are used in large gears, in addition to the familiar requirements like viscosity, viscosity index, pour point, aging behavior, there are numerous other test requirements nowadays designed to assess the oil's suitability in terms of its anti-corrosion and anti-wear properties, plus its scuffing and micro-pitting resistance for the rolling bearings and toothings used. These tests include:

- Anti-corrosion tests
- FAG FE 8 Test
- FZG Scuffing Test
- FZG Micro-Pitting Test

The tests listed are met by many of the products currently on the market, both polyalphaolefin-based and polyglycol-based types. Restrictions on performance due to the presence of water are uncommon nowadays. This is dealt with in more detail below.

## Water protection

The polyglycols used as gear oils exhibit good water-solubility, thanks to their EO/PO ratio of 1:1. The anti-corrosion properties, which can be assessed using a variety of test procedures are accordingly of particular interest.

## Stirring procedure to DIN ISO 7120

The anti-corrosion properties of lube oils are determined with the stirring procedure using a round steel rod [01]. 300 ml of the oil under test are mixed by stirring with 30 ml of distilled water, corresponding to 10%, at 60°C, for a period of 24 hours. The corrosion occurring at the immersed round steel rod is graded from 0 to 3.

Mineral oils and polyalphaolefin oils achieve the required anti-corrosion properties by means of suitable corrosion inhibitors. Table 1 also evidences excellent anti-corrosion properties for the polyglycol gear oil under test.

## SKF EMCOR test ISO 11702

The SKF Emcor Test [02] was developed for assessing the anti-corrosion properties of lubricating greases. They are graded on a scale of 0 (no corrosion) to 5 (10% of the surface corroded).

Test Procedure	M 320 Rating	PG 320 – 2 Rating
<b>Stirring Procedure, 10% Water</b>	0	0
<b>EMCOR Test, 2% Water</b>	0 / 0	0 / 0
<b>EMCOR Test, 5% Water</b>	0 / 0	0 / 0

Table 2: Corrosion test results

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By reason of the test cycle involved, which features a standstill time of 140 hours, it is also of particular interest for assessing polyglycols.

The tests performed with 2% and 5% water exhibit no signs of corrosion (Table 2). By comparison: for lubricating greases, the rolling bearing industry accepts a corrosion rating of 1.

## The influence of water on polyglycols in rolling bearing lubrication

The influence of water in the lube oil on the wear behavior and the lifetime of rolling bearings is adequately known from various studies and publications in the rolling bearing industry. Fig. 2, from a publication of FAG [03], illustrates the influence of water on the relative bearing lifetime.

### Bearing lifetime—influence of water contamination

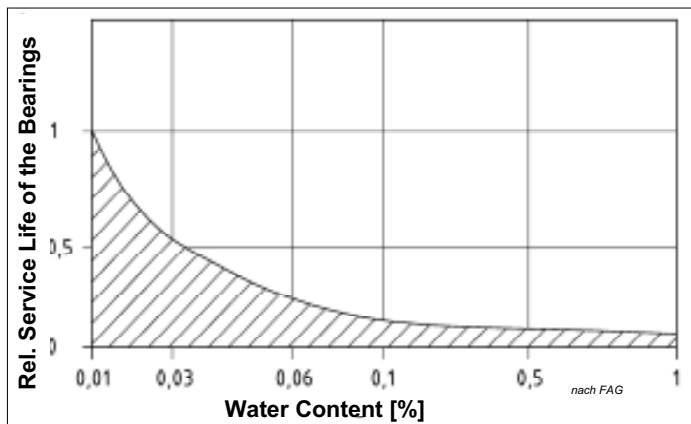


Fig. 2: FAG – the influence of water content on the relative lifetime of oil-lubricated rolling bearings

FAG's diagram shows that even very small quantities of water, in the range from 300 to 1000 ppm, significantly affect the bearing's lifetime. Possible variations in dependence on the base oil used, however, are not differentiated.

In addition, the Institute for Machine Elements at Aachen Technical University (IME), in a study dealing with the influence of moisture at grease- and oil-lubricated bearings [04], points to causal connections in terms of dissolved and free water, indicating that more favorable lifetime results can be anticipated with dissolved water contents.

Since water-soluble types are used with polyglycol gear oils, it is of interest to investigate possible deleterious influences in the presence of water for these types.

## FAG FE 8 rolling bearing wear test

The FE 8 test rig developed by FAG [05] serves not least to investigate the anti-wear properties of lubricants under extreme mixed-friction conditions.

This test, developed for lube oils, and lasting more than 80 hours, is conducted at a test temperature of 80°C. Under these conditions, the  $\kappa$ -value is in the range of 0.04 – 0.06.

The targets are rolling element wear of less than 30 mg and cage wear of less than 100 mg.

The results shown in Fig. 3 compare the performance of a polyglycol of ISO VG 320 without water, and the performance of the same polyglycol after admixture of 1% and 5% of water.

Even when 5% of water has been admixed, the rolling element wear is still significantly below the limit value of 30 mg. For cage wear, even lower wear rates were determined.

### FAG FE 8 test—wear test results

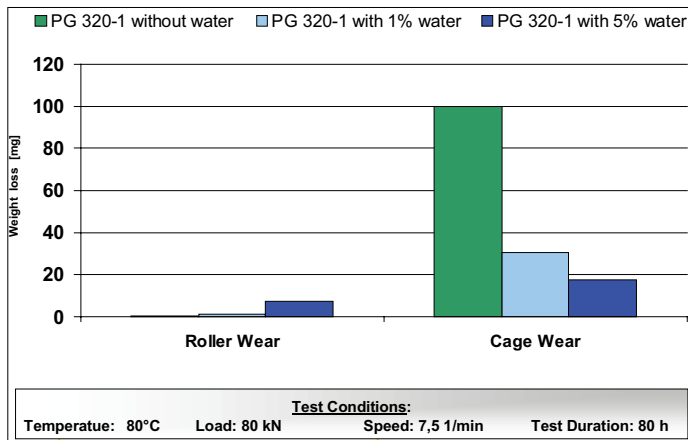


Fig. 3: FE 8 rolling bearing wear with admixture of water

### Rolling bearing lifetime

In order to determine possible influences of the lubricant on the bearing's lifetime, life tests are required. In conjunction with the Institute for Machine Elements (IME) in Aachen, life tests were accordingly conducted on a radial-bearing test rig.

### IME RLP test—test rig

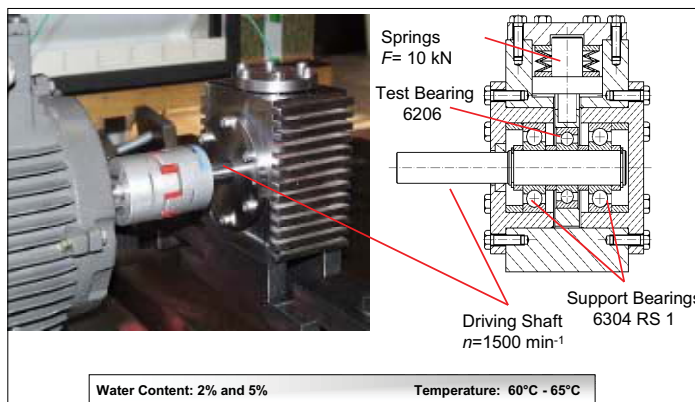


Fig. 4: IME RLP Test

The studies at the IME were designed to discover what influence water has on lubrication with polyglycols. For comparison purposes, studies were also carried out with a mineral oil.

The grooved ball bearing 6206 used is loaded with a spring washer component exerting a defined 10 kN. The speed is 1500 1/min. Under these EHD conditions, a bearing lifetime of 673 h was determined, which due to the kappa value of > 4 applies both for the mineral oil and for the polyglycol (Fig. 4).

The results (Fig. 5) show that when 2% of water is admixed (20,000 ppm), there is no measurable influence on the bearing's lifetime. Random-sample testing with 5% of water in the polyglycol revealed a 70% reduction in bearing lifetime if the water is dissolved. If the water is not dissolved, only 8% of the mathematical lifetime is reached. The mineral oil with 2% reaches 10% of the calculated lifetime in the random-sample test. The result thus agrees with those reported by the rolling bearing industry.

### IME RLP test—life time test results

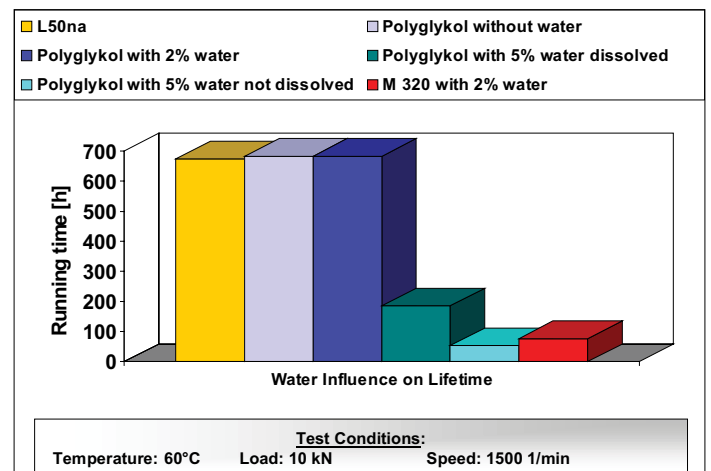


Fig. 5: IME RLP Test: water's influence on the relative bearing lifetime

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## Scuffing load capacity

From the studies carried out by Bayerdörfer [06] at the FZG regarding the influence on the tooth profile load-carrying strength of operationally entailed changes to the lubricant, it is known that the toothing, too, can be prematurely damaged by water in the oil.

Bayerdörfer's basic studies, too, were conducted with mineral oil, so that no conclusions can be drawn in regard to polyglycols.

In initial trials, the scuffing behavior of polyglycols with a water content of 5% was accordingly determined in an FZG Special Test, A10/16,6R/60. The test conditions were selected so as to ensure that when the 10-mm-wide wheel set is used the sump temperature adjusts itself to max. 75°C when the wheel is driving.

By comparison, a mineral oil with likewise a 5% water content was also tested. For both oils, it was known that they pass the standard FZG Scuffing Test with a load stage of > 12. The smaller gearwheel width of 10 mm instead of the customary 20 mm gearwheel width thus made it possible to run the test under extreme scuffing conditions, which meant that scuffing could already be anticipated at a relatively low load.

The tests revealed that the polyglycol gear oil without water fails in the test by reason of scuffing in load stage 7. By contrast, the mineral oil reaches the scuffing load stage by reason of its additive content in load stage 11, as expected.

The experiments with water admixture, conversely, show a changed picture. As in the reference run, the damage occurs in load stage 7 for polyglycol with 5% of water.

The mineral oil, by contrast, has already failed in load stage 10 (Fig. 6).

## FZG scuffing test—special test A10/16,6R/60

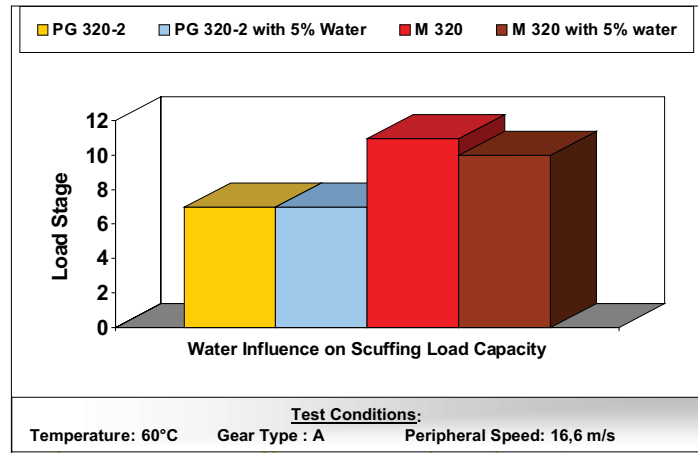


Fig. 6: Results of the FZG Scuffing Test

For the polyglycol, there are no detectable changes afterwards. For the mineral oil, the change is slight.

## Friction behaviour of polyglycols on the FZG test rig

Polyglycols score in terms of their very low friction coefficients. This favorable behavior is of particular utility for worm gears. In the case of spur gears, it is frequently argued that these low friction coefficients produce only slight improvements or none at all.

In the Klüber FZG Efficiency Test, the power loss is determined with Toothing A at the standard circumferential velocity and high torque.

## Friction behavior—Klüber FZG efficiency test

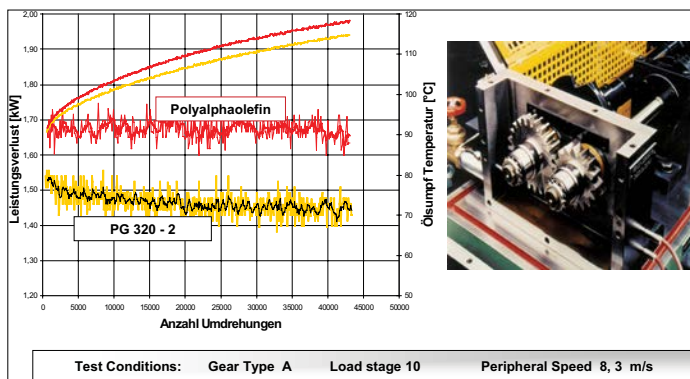


Fig. 7: Efficiency losses in dependence on various lube oils

Analysis of the test run shows a clearly measurable reduction in power loss. For the polyglycol, a 15% reduction in power loss is evidenced. The reduced power loss means first of all a lower oil sump temperature, and thus an extended oil lifetime.

When the change in power loss is converted into an efficiency figure, the toothings' efficiency is improved by approx. 0.2%. In a multi-stage large gear with a power throughput of several 100 kW, this seemingly modest improvement leads to a measurable decrease in power consumption.

## Summary

In large gears, the use of synthetic gear oils cannot be dispensed with. When polyglycols are used, there are uncertainties regarding how to factor in their effects on elastomers and their behavior in the presence of water. The paper describes the special features of polyglycols in regard to their water-solubility.

The dynamic seal compatibility tests presented show good compatibility with NBR and FKM elastomers for the polyglycol tested as well. The tests conducted over a period of 1000 hours produce results comparable to those for mineral oil.

Since in gear construction it is predominantly water-soluble polyglycols which are used, the influence of water on polyglycols was examined. The results obtained show that the oils tested are still able to meet CLP requirements, even with a high water content.

This does not mean that lubrication with water-content polyglycols should be permitted in all cases. The results merely demonstrate that the effects for polyglycols in conjunction with water need not be regarded as more critical in terms of function than for mineral oils. If water penetrates into the system unintentionally, polyglycol might even offer slight advantages.

In addition, the low friction coefficient of polyglycols offers an option for achieving extended oil lifetimes thanks to lower gear sump temperatures. The power consumption involved can be measurably reduced.

For more information, please contact Klüber Lubrication at [marketing@us.kluber.com](mailto:marketing@us.kluber.com).

White Paper

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Innovative tribological solutions are our passion. Through personal contact and consultation, we help our customers to be successful worldwide, in all industries and markets. With our ambitious technical concepts and experienced, competent staff we have been fulfilling increasingly demanding requirements by manufacturing efficient high-performance lubricants for more than 80 years.