



POLYGLYCOLS

FOR LUBRICATING LARGE GEAR DRIVES

Long used for the successful lubrication of worm gears, polyglycol-based synthetic oils now present a viable option for large enclosed gear drives.

by Hermann Siebert and Ulrich Mann, Ph.D.

Introduction

In modern-day gear technology, the lube oil used is an important element of 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 now necessitate the use of synthetic oils.

Although the feedback regarding the use of synthetic gear oils based on polyglycol has been positive, 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
M 320	320	95	Min	High additive content CLP FZG A/16,6/90>13
PG 320-1	320	> 230	PG	High additive content CLP FZG A/16,6/90>13
PG 320-2	320	> 220	PG	Additive package approved for the food industry 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 that 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.

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, or 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 percent 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, or are hygroscopic. This hygroscopicity, too, is influenced significantly by the type of polyglycol involved.

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

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 2,000 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 1,000 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 buildup
- 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.

Polyglycol Properties: 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, and aging behavior, there are numerous other test requirements used nowadays that are 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 these days. 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 percent, at 60°C, for a period of 24 hours. The corrosion occurring at the immersed round steel rod is graded from zero to three.

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 zero (no corrosion) to five (10 percent of the surface corroded).

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 percent and 5 percent water exhibit no signs of corrosion (Table 2). By comparison: for

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† Dr. Takemasu's paper on P/M Gear Finishing appeared the February '04 issue of *Gear Solutions* magazine

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lubricating greases, the rolling bearing industry accepts a corrosion rating of one.

Water in 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. 1, from a publication of FAG [03], illustrates the influence of water on the relative bearing lifetime.

FAG's diagram shows that even very small quantities of water, in the range from 300 to 1,000 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.

Test procedure	M 320 Rating	PG 320-2 Rating
Stirring procedure, 10% water	0	0
EMCOR Test 2% water	0 / 0	0 / 0
EMCOR Test 5% water	0 / 0	0 / 0

Table 2 — Corrosion Test Results

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 k-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. 2 compare the performance of a polyglycol of ISO VG 320 without water, and the performance of the same polyglycol after admixture of 1 percent and 5 percent of water.

Even when 5 percent 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.

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 IME, life tests were accordingly conducted on a radial-bearing test rig. 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.

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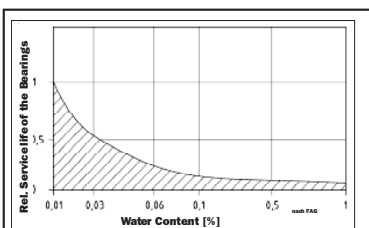


Figure 1 — FAG: the influence of water content on the relative lifetime of oil-lubricated rolling bearings

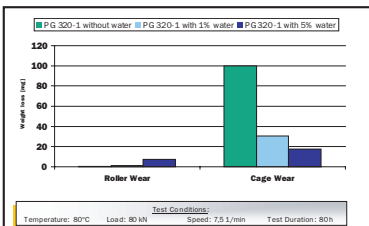


Figure 2 — FE 8 rolling bearing wear with admixture of water

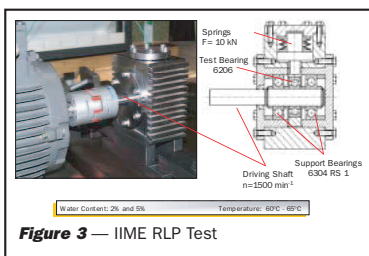


Figure 3 — IIME RLP Test

1,500 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. 3).

The results (Fig. 4) show that when 2 percent of water is admixed (20,000 ppm), there is no measurable influence on the bearing's lifetime. Random-sample testing with 5 percent of water in the polyglycol revealed a 70 percent reduction in bearing lifetime if the water is dissolved. If the water is not dissolved, only 8 percent of the mathematical lifetime is reached. The mineral oil with 2 percent reaches 10 percent of the calculated

lifetime in the random-sample test. The result thus agrees with those reported by the rolling bearing industry.

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 percent 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 percent water content was also tested. For both oils, it was known that

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they pass the standard FZG Scuffing Test with a load stage of > 12. The smaller gear-wheel 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.

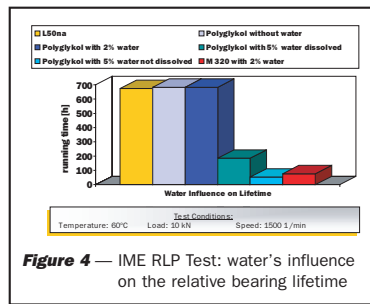
The tests revealed that the polyglycol gear oil without water fails in the test by reason of scuffing in load stage seven. By contrast, the mineral oil reaches the scuffing load stage by reason of its additive content in load stage 11, as expected.

The experiments with water admixture, conversely, show a changed picture. As in the reference run, the damage occurs in load stage seven for polyglycol with 5 percent of water. The mineral oil, by contrast, has already failed in load stage 10 (Fig. 5).

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

Polyglycol Friction on the FZG Test Rig

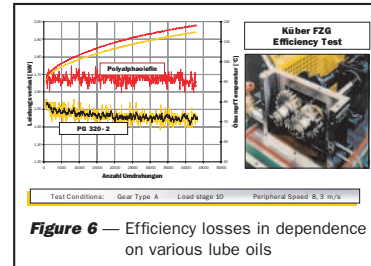
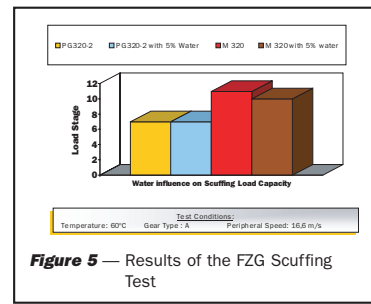
Polyglycols score in terms of their very



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.

Analysis of the test run shows a clearly measurable reduction in power loss. For the polyglycol, a 15 percent 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

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Battling Vapor Phase Corrosion in Idled Equipment

By A.G. Gustavsen, Ph.D.

Maintaining the operating integrity of idled equipment presents a totally different set of challenges than does maintaining equipment while it's in service. Equipment in service receives routine maintenance and continuous lubrication of internal components. All components of idled equipment are at static rest and receive no lubricant replenishment. More importantly, the internal cavities of the equipment collect water from condensation caused by the normal ingress and egress of air due to daily temperature fluctuations. Under these conditions, extensive rusting of bearings and other critical components can render the equipment totally inoperable in a surprisingly short period of time.

There are many reasons why equipment may be idled for extended periods of time. Cyclical market downturns or labor actions can cause individual operating units within plants to be shut down, and start-up delays on new projects can result in new equipment being stored for extended periods of time. Even new machinery subjected to salt air in trans-ocean shipments can accumulate rust on internal components before arriving at their destination. Regardless of why equipment is idled, vapor phase corrosion inhibitors (VPIs) provide a simple and inexpensive way to

protect the internal components of idled equipment against damaging rust and corrosion.

VPIs protect metal surfaces against rust in gear boxes, engines, and other closed systems. The inhibitor fills the closed spaces with a vapor that forms a monomolecular protective layer on all metal surfaces. This layer passivates metal surfaces to prevent rust and corrosion. Because the system is sealed, the protective layer is constantly maintained. The length of time the protection continues depends on how well the system is sealed, but protection upwards of one year is attainable.

Although the name "vapor phase corrosion inhibitors" seems to indicate that the inhibitor is in the form of a gas, VPIs actually have surprisingly low vapor pressures and are solids or liquids at room temperature. The most common form of VPI is a salt of an amine and a weak acid. An example would be the carbonate salt of dicyclohexylamine. Research has shown that the VPI disassociates to the amine and the acid, and the two volatile components recombine on metal surfaces.

When oil containing a VPI is used to "mothball" a piece of equipment, it is best to fill the equipment to normal oil levels and run it for a short time. This distributes the oil to all surfaces normally wet by oil and helps to saturate the air inside the

equipment with the VPI components. The oil can then be drained back into the original container, leaving a small "puddling" of the preservative in the equipment. The drained corrosion inhibitor can then be reused on another piece of equipment and then another, etc. The equipment should then be sealed by whatever means is available, such as tape or shrink wrap, to keep the VPI in and humidity out. A desiccant breather can be used if large temperature and/or pressure changes are anticipated. When returning the stored equipment into service, it is normally unnecessary to flush the residual vapor phase inhibitor from the equipment before it is filled with new oil.

Vapor phase corrosion inhibitors are offered by any number of oil suppliers. Royal Purple's is known as VP Preservative Oil 10. Properly used, vapor phase corrosion inhibitors are an extremely economical and effective way to protect new or idled equipment against rust and corrosion. Manufacturers of blowers and gear boxes, etc., have had excellent results using them to protect new equipment from rusting in transit to customers. The adage that an ounce of prevention is worth a pound of cure certainly applies to the case for using vapor phase corrosion inhibitors.

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toothings efficiency is improved by approx. 0.2 percent. 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 1,000 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. 

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