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Lubricants for Wind Turbines

Gear Oils-Demands and Characteristics

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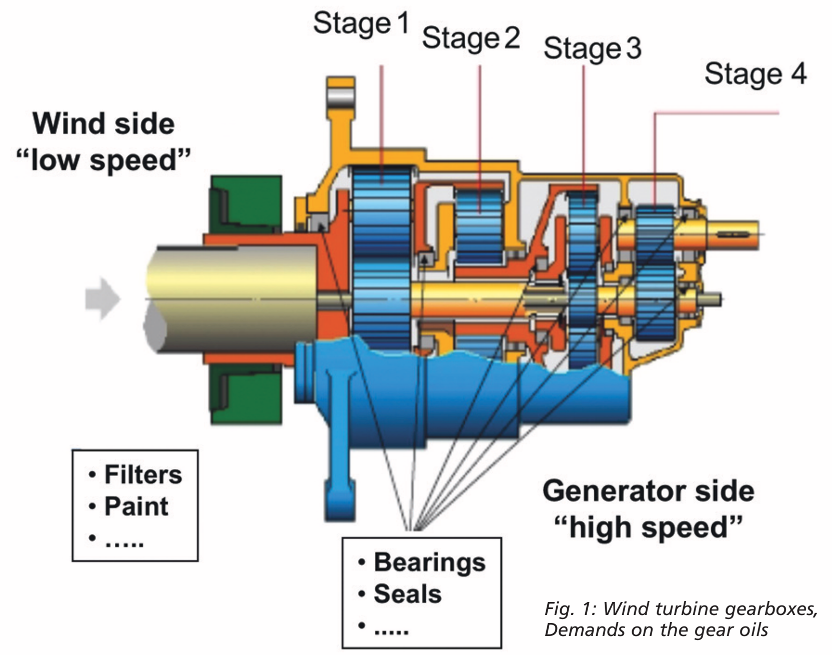


Fig. 1: Wind turbine gearboxes, Demands on the gear oils

1. Introduction

This article about the general and fundamental requirements and demands made on gear oils for wind turbines starts with an overview of the industrial gear oils market and covers the classification of industrial gear oils, their specifications and the current standardisation activities. Also covered are the demands on wind turbine gear oils, especially with regard to mechanical-dynamic and chemical tests. Moreover, the low temperature aspects of industrial gear oils for wind turbines are also dealt with.

As a rule, specially approved industrial gear oils are used for the main gears (ISO VG 320) – mostly multistage planetary spur gears, and for the azimuth gears (ISO VG 220). Viscosity selection is based on requirements of the gear tooth meshing (slow on the rotor side and fast on the generator side) and the requirements of the corresponding bearings. ISO VG 320 gear oils thus represent a compromise between the specific 'needs' of the planetary gears, the spur gears and the roller bearings. In addition, such gear oils have to satisfy special demands regarding compatibility with seals, paints, filters, corrosion preventives, running-in oils etc. (Figure 1)

2. Industrial Gear Oils – The Market

In 2011, industrial gear oil sales in Germany totalled 35,525 tonnes. Compared to the previous year (28,248 tonnes), this was an increase of about 25%. Industrial gear oils are thus an important part of the entire lubricants market. In terms of volumes, gear oil sales have returned to 2007 / 2008 levels. Of these volumes, mineral oil-based gear oils account for about 75-80% followed by fully-synthetic, PAO-based gear oils with a share of about 10-15%. The rest is made up by fully-synthetic gear oils based on polyglycols (about 5%) and synthetic ester oils and other special gear oils which make up less than 5%. There is a clear trend towards the use of fully-synthetic lubricants in gearboxes and drive-train components. Only these lubricants can fulfill the extreme technical demands of the machinery and thus the customers.

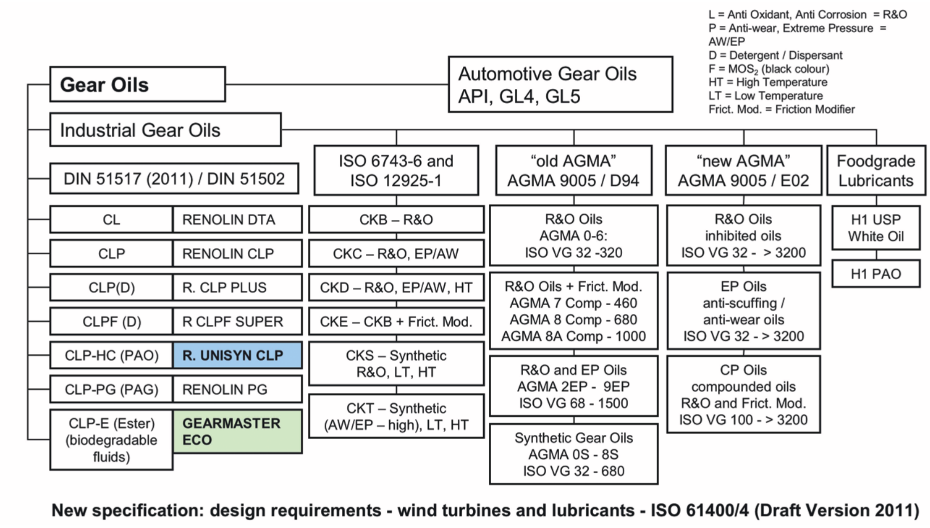


Fig. 2: Classification of Industrial Gear Oils

3. Classification of Industrial Gear Oils

The most important European standard for industrial gear oils is the German DIN standard 51517 issued in 2011. There are also other international standards such as ISO 6743, Part 6 together with ISO 12925-1. The new AGMA Standard 9005/E02 is also largely based on the DIN and ISO norms. It mainly describes physical thresholds as well as demands regarding wear protection of the tooth flanks, scuffing / scoring protection (FZG Test A/8, 3/90 according to DIN-ISO 14635-1). The requirements for roller bearings are based on the FE8 roller bearing wear test (according to DIN 51 819-3). Finally, a new specification for wind turbine gear oils is ISO 61400/4 (Figure 2).

4. Working Temperature Range and Life of Industrial Gear Oils

In very many cases, operators want to know details of the lubricant's maximum working temperature and expected service life. Such questions can only be answered with generally-applicable statements because numerous fringe and ambient parameters influence industrial gear oils and especially their service life. In general, it is best to observe the recommendations and experiences of the leading gearbox manufacturers. Figure 3 shows the Flender guidelines on working temperature range and service life at an median sump temperature of 80°C. Naturally, negative influences such as water (both free and dissolved), contaminants, assembly chemicals such as e.g. Loctite products, dirt, abrasion, wear and acidic gases need to be considered when evaluating the condition of an industrial gear oil or when calculating service life.

	according to Flender
Mineral oils, CLP-M:	**-10°C to 90°C (short periods 100°C)**
Polyglycols, CLP-PG:	**-20°C to 100°C (short periods 110°C)**
Polyalphaolefins, CLP-PAO:	**-20°C to 100°C (short periods 110°C)**
Synth. Ester („Bio"), CLP-E:	**-15°C to 90°C**

Lifetime at an average oil temperature of 80°C (according to Flender)

Mineral oils, CLP-M:	**2 years or 10.000 h**
Synth. Ester („Bio"), CLP-E:	**2 years or 10.000 h**
Polyglycols, CLP-PG:	**4 years or 20.000 h**
Polyalphaolefins, CLP-PAO:	**4 years or 20.000 h**

Contaminations (e.g. water, dirt, abrasion / wear products, acidic gases, etc.) have a negative influence on the lifetime.

The oil lifetime depends on the operating conditions

Fig. 3: Working Temperature Range and Life of Industrial Gear Oils (according to Flender)

5. Base Oils for Industrial Gear Oils

The most important base oils for wind turbine gear oils are fully-synthetic polyalphaolefins (PAO). These fully-synthetic base oils can be manufactured with defined chemical structures by synthesis. To optimise elastomer compatibility and additive solubility, PAO formulations usually contain polar, e.g. ester oil components (about 15-20% ester oil). These polar components keep additives, additive reaction products and ageing by-products in solution. Polyalphaolefins display very good low-temperature behaviour as well as excellent viscosity-temperature behaviour. Their high Viscosity Index is generally shear stable with insignificant shearing losses of about 1-2% in the DIN 51 350-6 taper bearing shear test. Polyalphaolefins also have a very low coefficient of friction and are usually miscible and compatible with mineral oils whereby residual mineral oil when changing over should not exceed 10% because otherwise, in certain circumstances, the mineral oil could have an excessive impact on the performance of the PAOs.

A niche group among wind turbine gear oils is those based on saturated, synthetic esters. Compared to mineral oils and polyalphaolefins, these offer rapid biodegradability of over 60% after 28 days in the OECD 301C test and are thus an alternative to conventional hydrocarbon oils in ecologically sensitive applications.

Ester oils have a very high Viscosity Index and their viscosity-temperature behaviour is generally good. The products are also shear stable with shearing losses of 1-2% in the taper bearing shearing test being insignificant. Ester oils have powerful self-cleaning properties due to their high polarity. This polarity keeps ageing by-products and contaminants in suspension until they are trapped in corresponding filters.

Property	Method	Unit	Requirement
Internal Coating Compatibility	Mäder		
P22-8050 Anthracene Brown			pass
Nuvopur Aqua Primer 510.1.6.1400			pass
Liquid Sealing Compatibility	Henkel		
Loctite 128068			pass
Static Elastomer 72NBR902 (100°C, 1008 hrs)	ISO 1817		
Δ Hardness Shore A		pts	-5 to +5 (+7)
Δ Volume		%	-2 to +5 (+6)
Δ Tensile Strength		%	-50 to +20
Δ Rupture Elongation		%	(-65) -60 to +20
Pass/Fail comment			pass
Static Elastomer 75FKM585 (110°C, 1008 hrs)	ISO 1817		
Δ Hardness Shore A		pts	-5 to +5 (+7)
Δ Volume		%	-2 to +5 (+6)
Δ Tensile Strength		%	-50 to +20
Δ Rupture Elongation		%	(-65) -60 to +20
Pass/Fail comment			pass
Dynamic Elastomer 72NBR902 (80°C, 1000 hrs)	DIN 3761		
Leakage	Freudenberg	ml	0
Sealing Time		hrs	1008
Wear band width on sealing edge		mm	≤ 0.5
Depth of shaft wear		µm	≤ 5
Radial load with spring		%	+10 to -45
Interference with spring		mm	≤ 0.6
Interference without spring		mm	≤ 0.7
Visual assessment of sealing edge			
Dynamic Elastomer 75FKM 585 (90°C, 1000 hrs)	DIN 3761		
Leakage	Freudenberg	ml	0
Sealing Time		hrs	1008
Wear band width on sealing edge		mm	≤ 0.4
Depth of shaft wear		µm	≤ 10
Radial load with spring		%	+10 to -35
Interference with spring		mm	≤ 0.5
Interference without spring		mm	≤ 0.6
Visual assessment of sealing edge			
Micropitting Test (Grey Staining)	FVA 54 (I-IV)		
Load stage fail		fail load	≥ 10
Load stage GFT rating		GSC	high
Endurance stage GFT rating		GSC	high
FZG Scuffing (A/8.3/90)	ISO 14635-1		
Load stage		fail load	> 12
FZG Scuffing (A/16.6/90)	ISO 14635-1		
Load stage		fail load	by agreement > 12
FE-8 Bearing	DIN 51819-3		
Rollers weight loss		mg	< 30
Cage weight loss		mg	Report
Flender Foam Test	GG-V 425		
Original Oil			
Volume at T1		%	≤ 15
Air - Oil Dispersion at T5		%	≤ 10
Original Oil + 2% Castrol Alpha SP220S			
Volume at T1		%	≤ 15
Air - Oil Dispersion at T5		%	≤ 10
Original Oil + 4% Castrol Alpha SP220S			
Volume at T1		%	≤ 15
Air - Oil Dispersion at T5		%	≤ 10

Table. 1: Siemens Flender Specifications for Industrial Gear Oils (Revision 13) – Excerpt

6. Demands on Wind Turbine Gear Oils

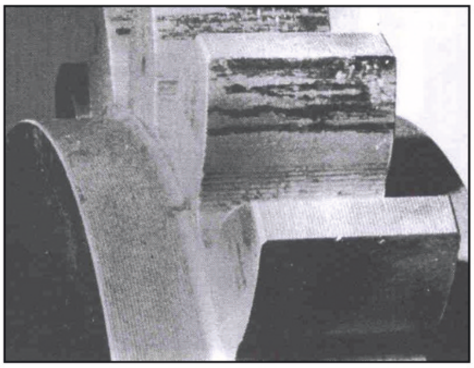
Of all the demands on gear oils, the Siemens Flender specifications are viewed as fundamental requirements and are among the most important together with DIN 51 517,Part 3 (Table 1). Prominent among the physical/chemical demands are compatibility with internal gearbox paints, static elastomer tests (NBR – 100°C, 1008 h, FKM – 110°C, 1008 h) and the Freudenberg dynamic elastomer test. Experience has shown that compatibility with gearbox paints under specific test conditions is not an unimportant factor. Paint compatibility is affected by the base oil as well as by the additives and their components. As regards seals, FKM materials are relatively uncritical. NBR compatibility is a problem insofar as the corresponding tests are carried-out at very high temperatures for 1008 hours (a drop in test temperature to 95°C is planned). The dynamic tests are performed in line with Freudenberg in-house procedures. At present, a Working Group is examining the demands, test temperatures and test durations and a change to the current demands and test parameters is currently under discussion. Apart from Flender and Freudenberg, a number of leading lubricant and additive manufacturers are represented in this Working Group to discuss and perhaps practically modify the present specifications.

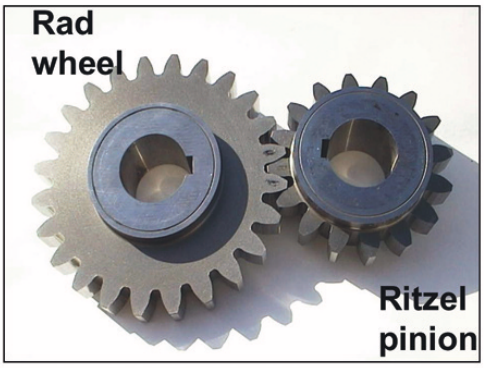
In addition, important mechanical-dynamic tests – demands on wind turbine gear oils with regard to micro-pitting and scuffing avoidance (standard test and test with higher speeds), roller bearing wear test FE8 as well as diverse Flender foam tests, also with corrosion preventive contamination should also be mentioned.

Of particular significance is good micro-pitting protection as well as scuffing prevention / protection. Scuffing prevention influences gearbox design, i.e. gears are designed considering the Hertzian stress in rolling contact (pitch point) according to FZG scuffing tests (DIN-ISO 14635-1). The same applies to roller bearing selection. The corresponding FE8 test parameters are defined in the area of extreme mixed friction at very high axial loads and high oil temperatures.

An important selection criterion for industrial gear oils is the protection of the teeth against micro-pitting. Any gear oils used must offer a high degree of protection against micro-pitting. This property is tested according to FVA 54 I-IV with the therein specified C-meshing, pitch line velocity of 8.3 m/s and oil injection temperatures of 90°C and 60°C. Micro-pitting is tested in both a load stage test as well as an endurance test. In the load stage test, the median tooth profile deviation must be less than 7.5 µm and the maximum threshold for the endurance test is 20 µm. Also, the tooth profile deviation must not increase under load. Figures 4 and 5 show an overview of the demands regarding micro-pitting for industrial gear oils for wind turbines.

Scuffing is generally tested with the FZG test according to DIN-ISO 14635-1. The standard scuffing test, performed at a pitch line velocity of 8.3 m/s and an initial oil sump temperature of 90°C, can be run at up to load stage 14 which is equivalent to a Hertzian stress of 2138 N/mm². This test highlights the highly positive influence of fully-synthetic gear oils based on polyalphaolefins. Low coefficients of friction, a high Viscosity Index and optimum mechanical efficiency can lead to a possible lowering of oil sump temperatures by about 20°C at correspondingly high loads when compared to mineral oils. This means that fully-synthetic, polyalphaolefin-based gear oils offer lower power losses and better efficiency under load in comparison to mineral oils. This leads to an increase in the load-bearing viscosity. Lower oil sump temperatures are also recorded in practice. A drop in oil sump temperature in the gearbox housing of about 5-7°C was achieved in a wind farm when a CLP 320 mineral oil was replaced with a fully-synthetic, polyalphaolefin-based lubricant: RENOLIN UNISYN CLP 320. Other advantages included high viscosity at equivalent operating conditions, greater lube film stability, less oxidation and longer service life of the fully-synthetic gear oil (Figures 6 and 7).





FVA 54 I-IV – C/8,3/90, C/8,3/60

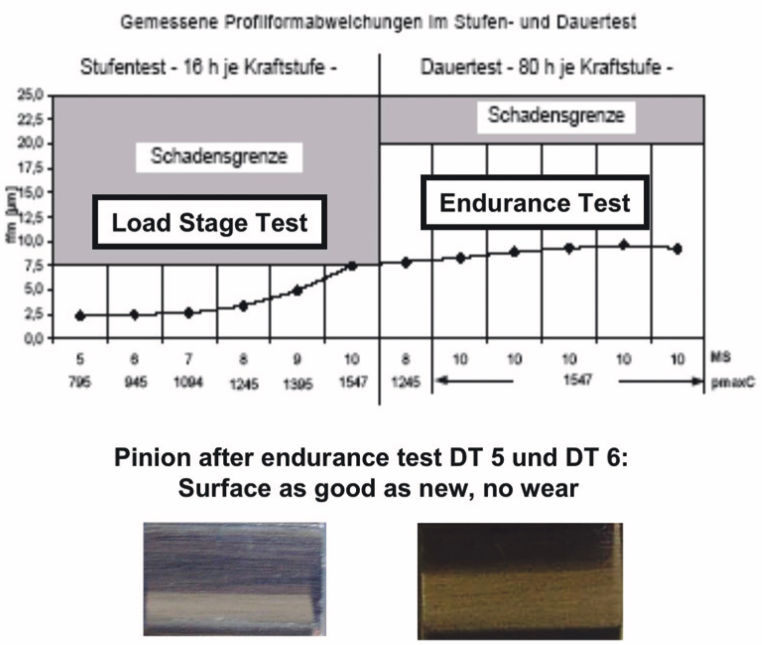
Test conditions

- Gear geometry: C type (14 mm)
- Pitch line velocity 8.3 m/s
- Temperature: 90°C or 60°C, - constant (stabilized)
- Oil-spray lubrication (2l/min, ca. 25 l)
- Load (total test duration ca. 580 h = 24 d)
  - ⇨ Load stage test: running-in (1h at load stage 3)
    16 h / load stages 5-10 (96h)
  - ⇨ Endurance test: 80 h at load stage 8
    5 x 80 h at load stage 10

Test results:

- Inspection of pinion and wheel after each load stage (in the load stage test, and every 80 h in the endurance test)
  - ⇨ Profile deviation of 3 tooth flanks (max. 7,5 µm in the load stage test, max. 20 µm in the endurance test)
  - ⇨ and / or micro-pitting area at 3 tooth sets and wear in mg (micro-pitting area < 20%: micro-pitting class high)

Fig. 4: Micro-Pitting Test According to FVA 54 I-IV – Test Parameters



ST = Load Stage Test

Prüfergebnisse der einzelnen Prüfabschnitte

Prüfstand : FZG02 Beginn des Prüflaufes am : 08.03.2002
Radsatznr. : 493_R Ende des Prüflaufes am : 09.08.2002

Lauf	MS	T1t	Dauer [h]	GF-RI [%]	W-RI [mg]	ffm -RI [µm]	Datum
1. ST	5	70.0	16	0	2.9	2.4	08.03.2002
2. ST	6	98.9	16	0	3.1	2.5	16.03.2002
3. ST	7	132.5	16	0	3.3	2.6	27.03.2002
4. ST	8	171.6	16	0	5.6	3.4	06.04.2002
5. ST	9	215.6	16	0	9.2	4.9	24.04.2002
6. ST	10	265.1	16	**0**	**16.9**	**7.5**	07.05.2002
1. DT	8	171.5	80	0	18.2	7.9	17.05.2002
2. DT	10	265.1	80	0	19.5	8.3	14.06.2002
3. DT	10	265.1	80	0	23.7	8.9	01.07.2002
4. DT	10	265.1	80	0	24.0	9.3	16.07.2002
5. DT	10	265.1	80	0	28.5	9.6	29.07.2002
6. DT	10	265.1	80	**0**	**29.7**	**9.3**	09.08.2002

DT = Endurance Test

Fig. 5: Micro-pitting according to FVA 54 I-IV – Example of the test results with Fuchs Renolin Unisyn CLP 320

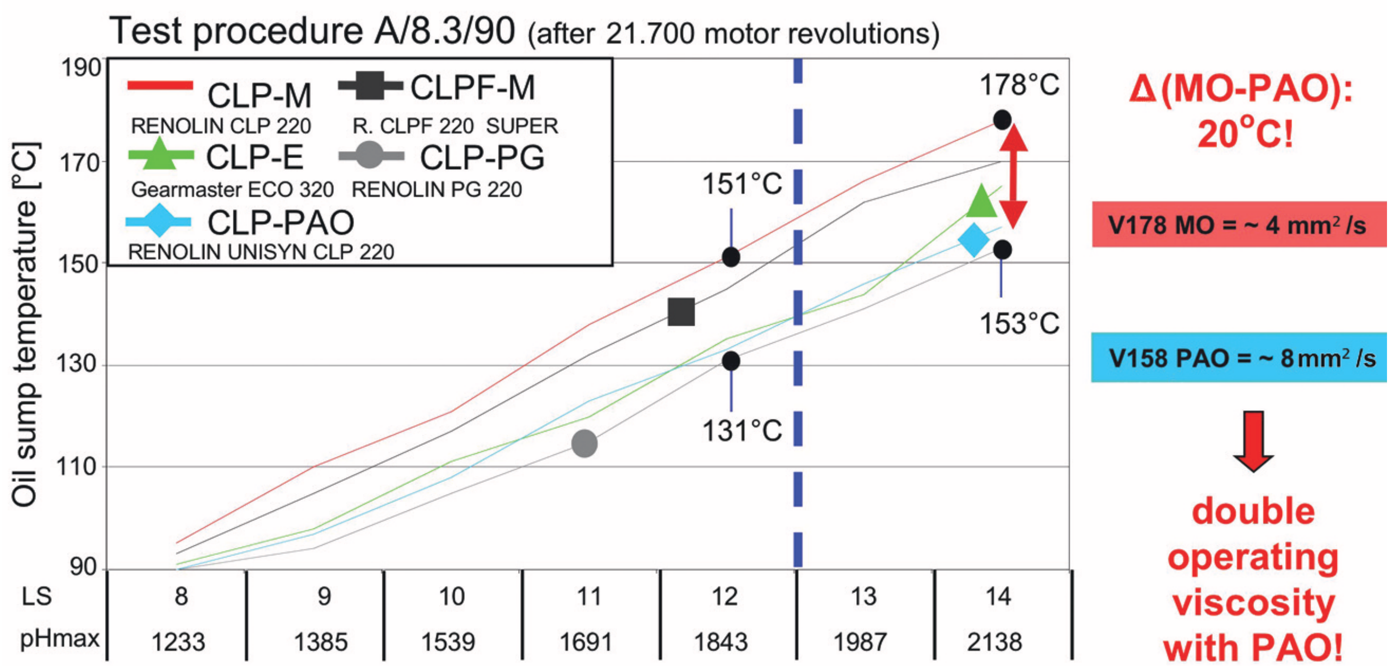


Fig. 6: FZG Scuffing test – Oil sump temperatures in the standard FZG A/8,3/90 test

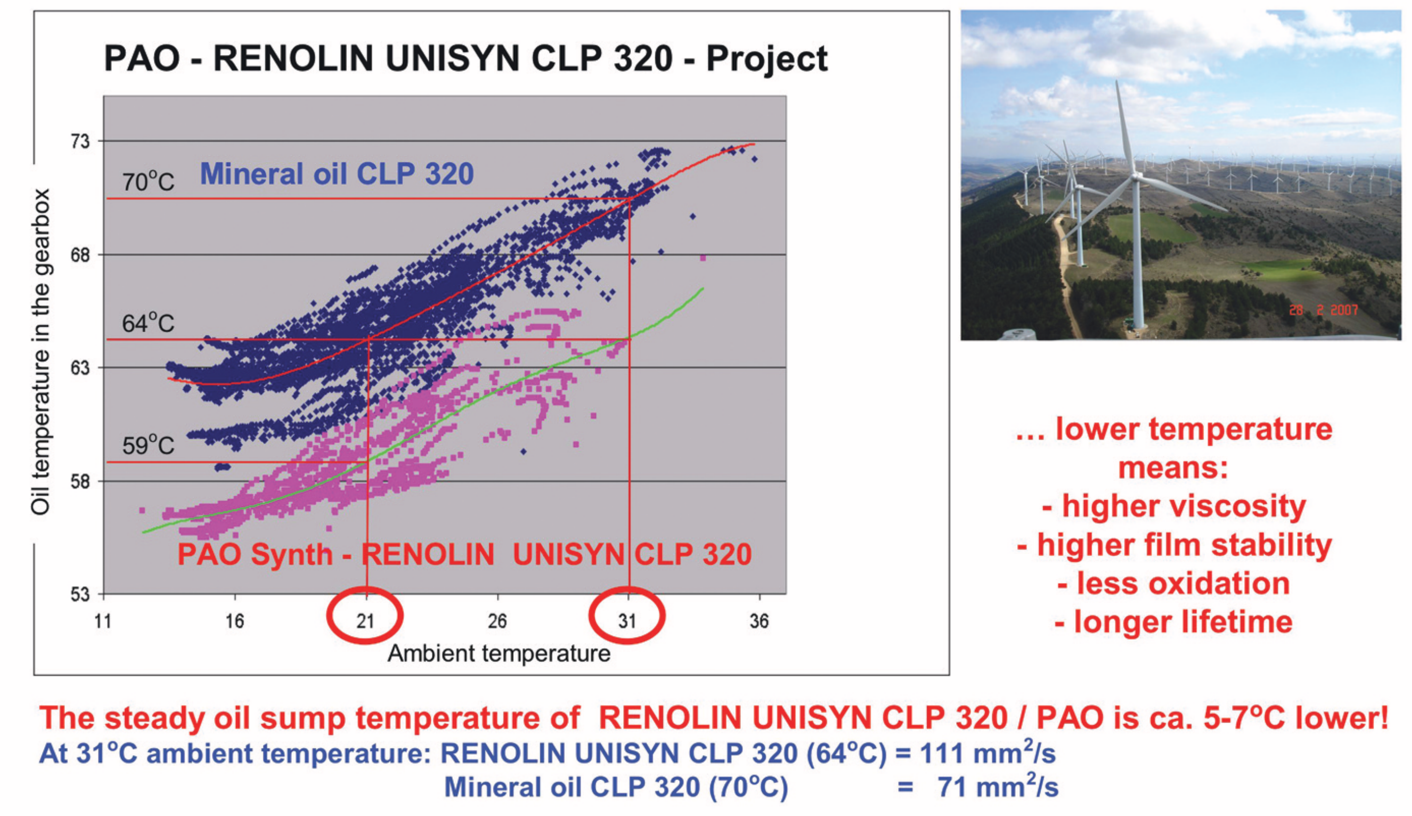


Fig. 7: Field test results – Wind turbine gear oils

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To be continued in LubeTech No.86