Polyalkylene Glycols (PAGs) as High-Performance Base Oil Components in Modern Greases

NLGI 2022

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Industrial Lubricants
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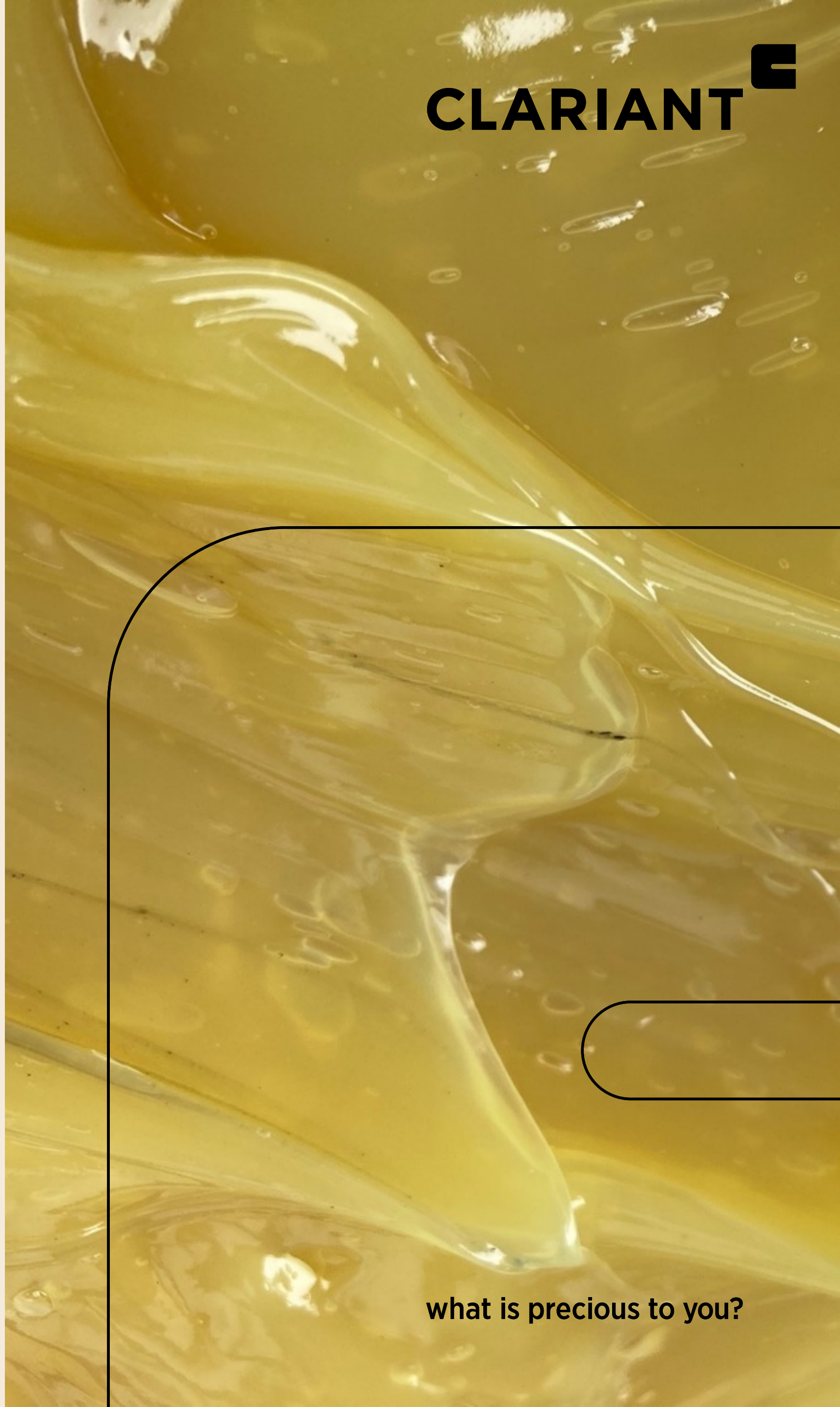

Agenda

- Defining components of a grease
- Grease production market
- **Polyalkylene glycols (PAGs)**
  - Chemistry
  - Performance overview
  - Lubrication properties
  - Temperature behavior
  - Oxidative stability
  - Material and oil compatibility
  - Interaction with water
  - Corrosion protection performance
  - Formulation examples

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Regional R&D Centres   Clariant Innovation Centre

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Care Chemicals	Catalysis	Natural Resources
Consumer Care	Industrial Applications	Base Products
Crop Solutions Industrial & Home Care Personal Care Active Ingredients Food Ingredients	**Industrial Lubricants** Paints and Coatings Construction Aviation	**EO/PO Derivatives** Softener Quats Sodium Laureth Sulfates

A grease is a solid or semisolid lubricant made by thickening base oils with gelling agents

Greases can be more than lubricants; they are often also used as sealants, corrosion inhibitors, shock absorbers and noise suppressants.

Typical key components of greases and their concentrations:

BASE OIL

(65–95%)

Mineral oils, esters, polyalkylene glycols (PAGs), polyalphaolefins (PAOs), silicone base oils (silicones), polyphenylethers (PPEs), perfluoroalkylethers (PFAEs)

THICKENER

(5–35%)

Soaps, bentonite, silica, polyurea, polytetrafluorethylene (PTFE)

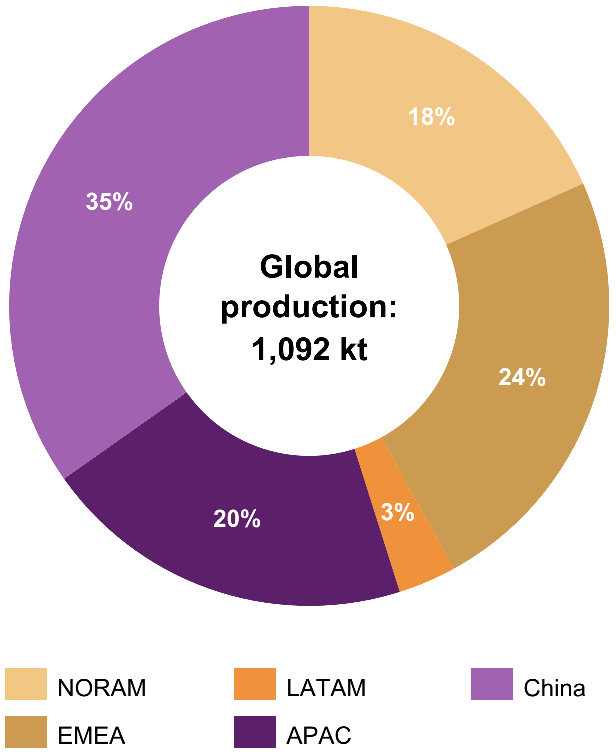
ADDITIVES

(0–10%)

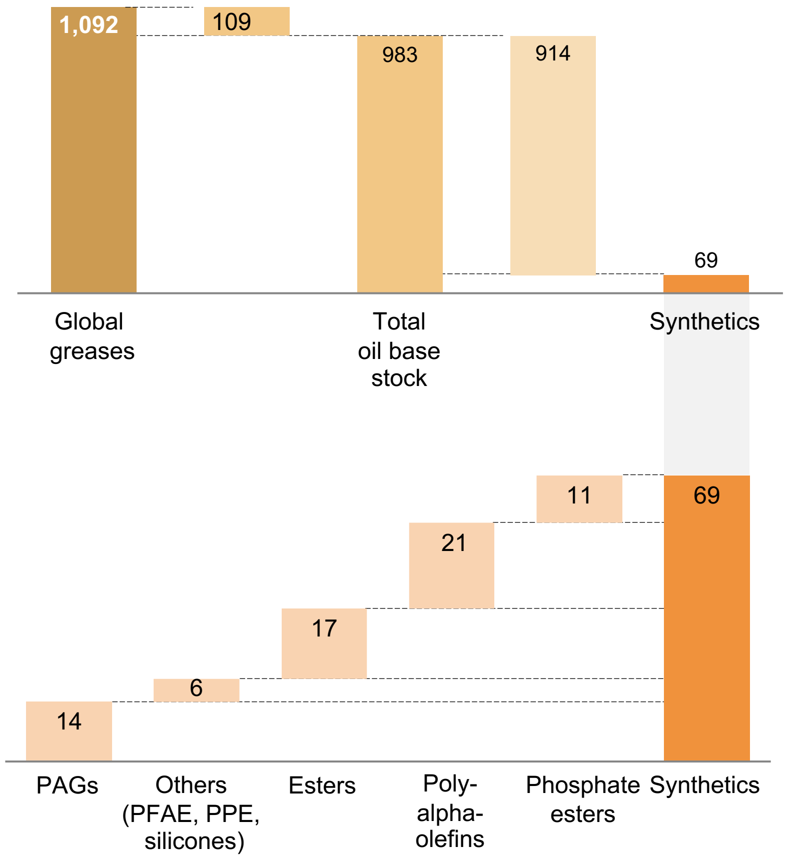
- Corrosion inhibitors
- Antioxidants
- EP/AW additives
- Lubricity improvers
- Solid lubricants (e.g., graphite, PTFE)

Around 6% of all greases are based on synthetic oils and lithium types dominate the thickener market

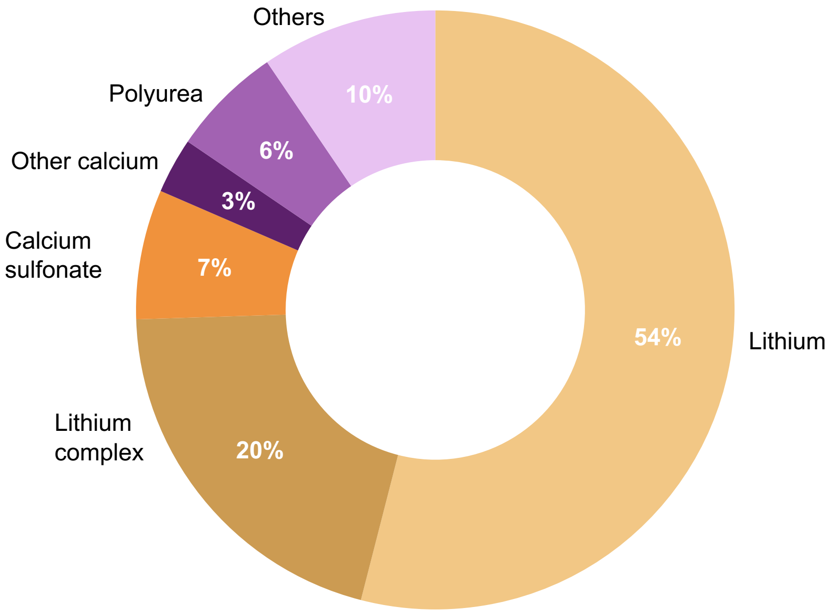
Grease production 2018 by region



Grease production 2018 in kt



Greases by thickener type 2017



Lithium types: With 2.3% CAGR, complexes cannibalize simple types (-1.8% CAGR) and other greases

Calcium types: With 12% CAGR, sulfonates are taking shares from lithium complexes

Polyurea: Global CAGR 2.2%, with highest share in Japan, long-life applications, and expected push from e-cars and wind power

Others: incl. calcium complex, bentonite, silica < 1% share

Sources: Internal Market estimation; NLGI Regional Production Split; NLGI Grease Production Survey 2017

Polyalkylene Glycols (PAGs): Synthetic polymers with highly adjustable properties

By varying factors like starting alcohol, amounts of ethylene and propylene oxide as well as catalysts used, PAG base oils can be precisely tailored to various requirements.

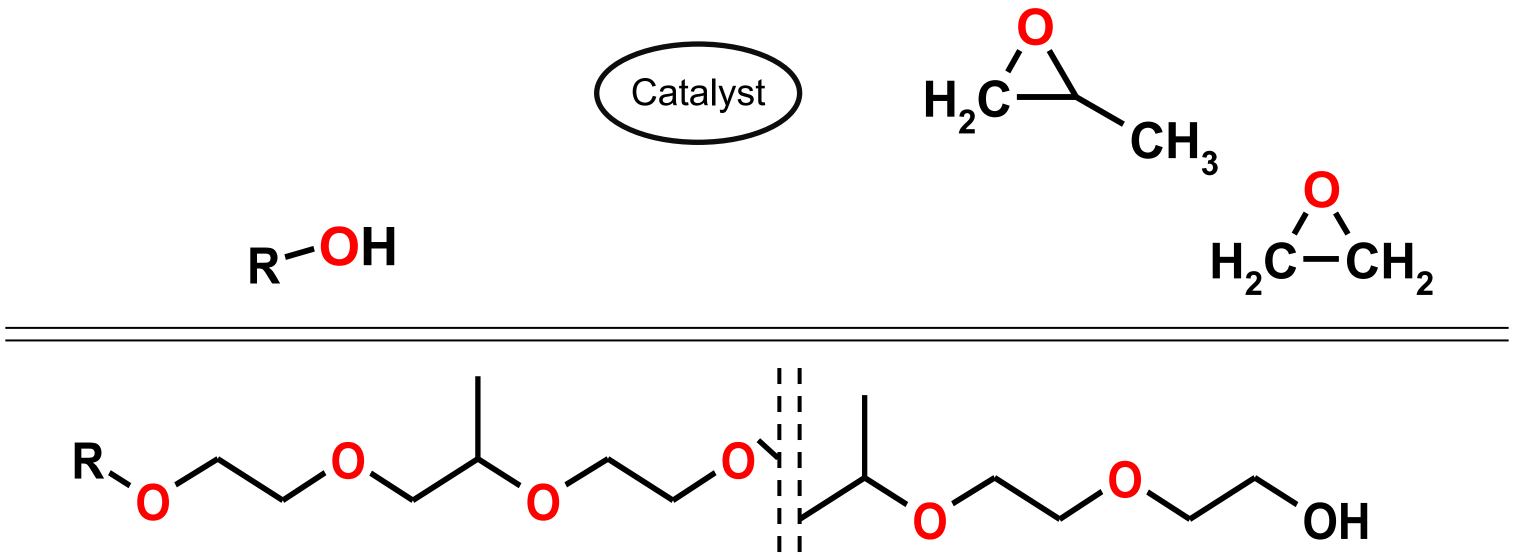
STARTING ALCOHOL

- Structure: linear or branched
- Number of functional groups

CATALYST

RELATION/AMOUNT OF EO AND PO

- Statistical/block copolymer
- M_w distribution



ADJUSTABLE PROPERTIES

- Viscosity
- Viscosity index
- Polarity/water solubility
- Freezing point
- Thermal properties
- Hydrodynamic friction
- Lubrication
- Various other properties

Polyalkylene Glycol (PAG) in grease applications
Performance properties compared

CATEGORY	PROPERTIES	RELEVANCY
High-temperature behavior →	Flash point [°C]	Manufacturing, use
	Thermo-oxidative stability (5% loss [°C]/middle point [°C]/R [%])	Manufacturing, use; faster wear due to deposits; safety, environmental hazards
Oil/oil and material compatibility →	Material compatibility	Insufficient compatibility can cause premature failure of components
	Oil/oil miscibility	Switch to other grease type can cause failure in performance; potential use as additive
Low-temperature behavior →	Pour point [°C]	Low-temperature applications
Lubrication properties →	Viscosity index	Temperature behavior, lubrication film thickness, load-carrying capacity
	SRV (friction coefficient μ, wear scar)	Lubrication, extreme pressure (EP)
Sustainability/compliance →	Biodegradability and ecotox/LuSC list	Fitness for use in EU Ecolabel greases
	Labeling	Reduced human toxicity and ecotoxicological hazards
	Food approved (NSF)	Fitness for use in H1 food-approved greases

LN = low naphthenic, MN = medium naphthenic, LP = low paraffinic, MP = medium paraffinic, LV = low viscous vegetable, LS = low viscous PAO, HS = high viscous PAO, LEP = low viscous polyol ester, LET = low viscous trimelliate, SRV (Schwingungs-Reibverschleiß) = wear from oscillation and friction, LuSC = Lubricant Substance Classification list, NSF = National Sanitation Foundation

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Polyalkylene Glycol (PAG) in grease applications

Performance properties compared

Performance: good medium poor

		HYDROPHOBIC PAGs		HYDROPHILIC PAGs		HYDROPHILIC PAG modified	
CATEGORY	**PROPERTIES**	**LOW VISCOUS**	**HIGH VISCOUS**	**LOW VISCOUS**	**HIGH VISCOUS**	**LOW VISCOUS**	**RELEVANCY**
High-temperature behavior ➔	Flash point [°C]	190–217	227–240	210–231	250	199	Manufacturing, use
	Thermo-oxidative stability (5% loss [°C]/middle point [°C]/R [%])	184/227/0 No residues	202/249/0 No residues	184/226/0,3 No residues	221/270/0 No residues	176/222/0 No residues	Manufacturing, use; faster wear due to deposits; safety, environmental hazards
Oil/oil and material compatibility ➔	Material compatibility	Nitrile butadiene rubber (NBR), 2-component epoxy-based primers, ethylene propylene diene monomer rubber (EPDM)					Insufficient compatibility can cause premature failure of components
	Oil/oil miscibility FULLY SOLUBLE	LN, MN, LP, LV, LEP, LET	LN, LV, LEP	LV, LET	–	LN, LV, LEP, LET	Switch to other grease type can cause failure in performance; potential use as additive
	PARTLY SOLUBLE	MP, LS	MN, LP, MP, LS	LEP	LET*	MN	
	INSOLUBLE	HS	HS, LET	LN, MN, LP, MP, LS, HS	LN, MN, LP, MP, LV, LS, HS, LEP	LP, MP, LS, HS	
Low-temperature behavior ➔	Pour point [°C]	-66 – -50	-45 – -36	-66 – -50	-50 – -35	-72	Low-temperature applications
Lubrication properties ➔	Viscosity index	132–185	191–270	170–208	208–298	210	Temperature behavior, lubrication film thickness, load-carrying capacity
	SRV (friction coefficient μ, wear scar)	0.140/0.784 mm Smooth run	0.126/0.584 mm Smooth run	–	0.107/0.560 mm Smooth run	0.122/0.636 mm Non-smooth run	Lubrication, extreme pressure (EP)
Sustainability/ compliance ➔	Biodegradability and ecotox/LuSC list	YES/NO	NO/NO	YES/YES	YES/YES	NO/NO	Fitness for use in EU Ecolabel greases
	Labeling	NONE	NONE	NONE (except > B 11/100)	NONE	NONE	Reduced human toxicity and ecotoxicological hazards
	Food approved (NSF)	NO	YES	NO	YES	NO	Fitness for use in H1 food-approved greases

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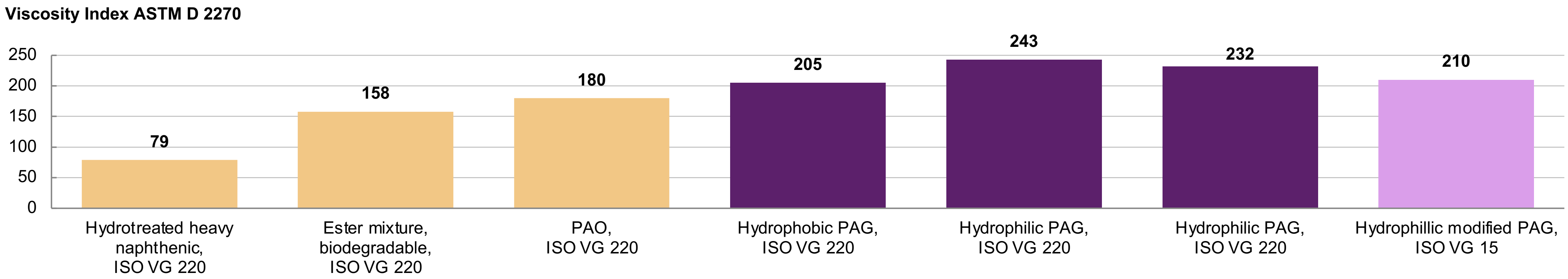
Lubrication properties – High viscosity indexes for high load tolerance

The viscosity index (VI) characterizes the viscosity-temperature behavior of lubricants



Applicability of greases over a wide range of temperatures

Polyalkylene glycols typically have very high VIs, enabling high load-carrying capacities

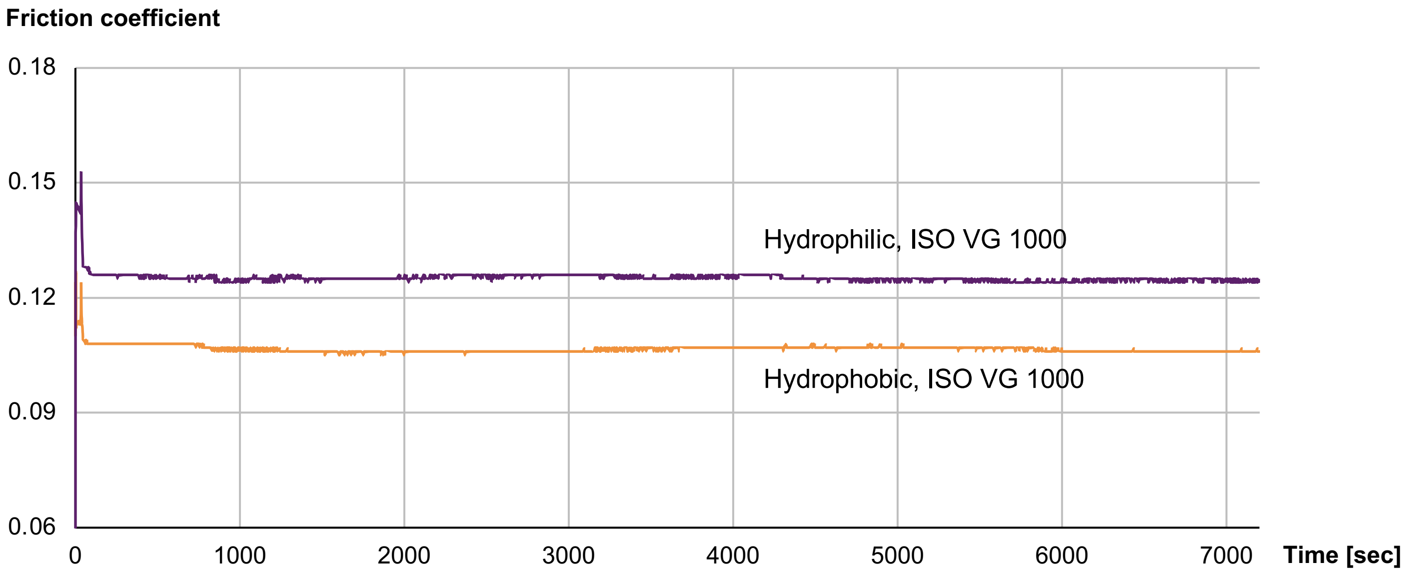
* modified

Lubrication properties – Superior results in friction and wear tests

SRV tests (*Schwingungs-Reibverschleiß)* are tribological tests measuring the friction and wear resulting from the oscillation of two specimens in loaded contact.

Common test for assessing lubrication properties according to standards ASTM D6425-11/DIN 51834-2:2010

TEST PARAMETERS
temperature: 50 °C, frequency: 50 Hz,
stroke: 1,0 mm, duration: 120 min, load: 300 N



POLARITY	CHEMISTRY	WEAR SCAR* W_k [mm]	μ^*_{min}	μ^*_{max}	μ^*_{15}	μ^*_{30}	μ^*_{90}	μ^*_{120}	FAILURE* (μ > 0.3)
Hydrophobic	ISO VG 15 PAG	0.784	0.110	0.192	0.130	0.139	0.144	0.146	–
	ISO VG 1000 PAG	0.584	0.125	0.128	0.127	0.127	0.127	0.126	–
	PAO	–	0.151	> 0.3	–	–	–	–	yes: 16 sec
	PAO	–	0.113	> 0.3	–	–	–	–	yes: 78 sec
Hydrophilic	ISO VG 15, modified PAG	0.636	0.100	0.198	0.110	0.119	0.128	0.135	–
	ISO VG 1000 PAG	0.560	0.105	0.125	0.107	0.107	0.108	0.108	–

*average of 2 runs

Closely simulates the operating conditions of lubricants

The Polyalkylene glycols achieve excellent results: low friction coefficients and wear scars

High-temperature behavior – Flash points that allow safe processing

Flash point (according to Cleveland Open Cup, DIN ISO 2592 – replaced DIN 51376):
The lowest temperature at which vapors above a volatile substance can form an ignitable mixture in air

Maximum safe temperature at which fluid can be processed during grease manufacturing

Most PAGs have a flash point above 200 °C, making them suitable for the manufacturing of complex soap grease

POLARITY	ISO VG	FLASH POINT [°C]
Hydrophobic	15	190
	32 – 46	~ 220
	100 – 1000	~ 240
Hydrophilic	22	210
	15	199
	46 – 220	~ 250
	220 – 1000	~ 250
	460 Star structure	270

High-temperature behavior – Thermo-oxidative stability and burn-off

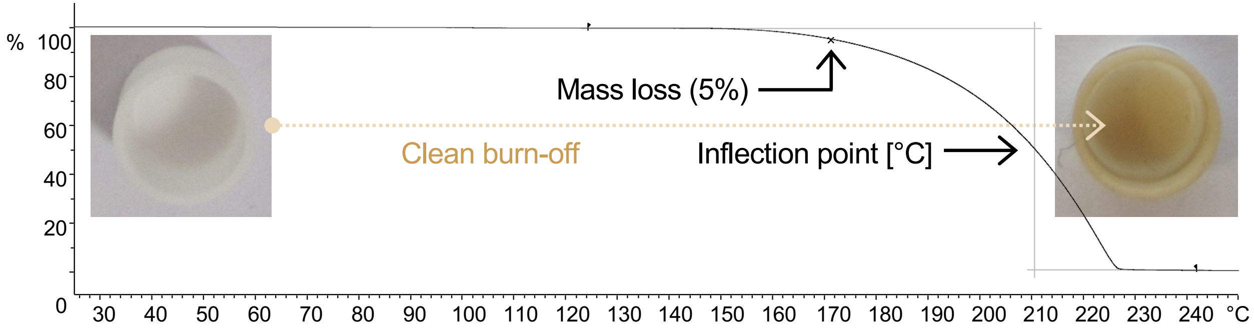
Heat under air flow (30 ml/min) from RT to 400 °C, heating rate 10 K/min

Maximum temperature at which fluid can be processed during grease manufacturing or used

Most PAGs have high inflection points and undergo a mass loss of 5% above 200 °C

All PAGs burn off cleanly

Thermo-oxidative resistance increases with ethylene oxide (EO) content and molecular weight – it can also be greatly improved by adding an antioxidant package



ISO VG	MASS LOSS (5%)	INFLECTION POINT (°C)	RESIDUES (%)
15, hydrophilic	184	227	0
15, hydrophobic**+ 3% additive package**	**201**	**258**	**0**
220, hydrophilic	210	259	0
220, hydrophobic	202	249	0

*Additive Package– antioxidant and EP/AW additive package

Low-temperature behavior – Pour points well below -50 °C possible

Pour point (according to DIN ISO 3016): The lowest temperature at which an oil still flows

Relevant for low-temperature applications

The pour point drops with increasing propylene oxide (PO) content and decreasing molecular weight

Hydrophobic PAGs reach pour points well below -50 °C

The lower viscosity hydrophobic PAGs and hydrophilic PAGs have excellent pour points

POLARITY	ISO VG	POUR POINT [°C]
Hydrophobic	15	-66*
	32 – 46	-50
	100 – 320	-40
	460 – 1000	-36
Hydrophilic	22 – 100	-50
	15, modified	**-72***
	150 – 220	-45
	220 – 1000	~ -35

*according to ASTM D 7346-14

Material and seal compatibility

EPDM compatibility (in analogy to ISO 4925): Average of two measurements, EPDM RM 69, 100 °C, 7 d

Prevents premature failure of materials

PAGs exhibit excellent compatibility with EPDM RM 69, elastomer NBR 28/SX, and 2-component epoxy-based primers M 20 and P22

ISO VG	ISO VG 46, hydrophilic PAG	ISO VG 15, hydrophilic PAG, modified	Requirements ISO 4925
Relative change in volume	**+0.9%** ✓	**+6.0%** ✓	min. 0% max. 10%
Change in hardness IRHD	**-3** ✓	**-6** ✓	min. -15 max. 0%

*contains additive package

Miscibility with other oils – Depends on polyalkylene glycol structure

Water solubility	Polyalkylene glycol	Naphthenic oil (ISO VG 22)	Paraffinic oil (~ ISO VG 15)	Vegetable oil (ISO VG 46)	PAOs (ISO VG 22)	Polyol ester (ISO VG 46)	Trimelliate Ester (ISO VG 46)
No	ISO VG 32				<20%/<10%*		
No	ISO VG 220		<30%/0%*		<10%/0%*		
Yes	**ISO VG 15**						
Yes	ISO VG 22					<10%/<10%*	
Yes	ISO VG 220			<5%/0%*			<20%/0%*
Yes	ISO VG 220						

*Basestock in polyalkylene glycol/polyalkylene glycol in basestock

Solubility: completely soluble soluble at certain concentrations insoluble

Switch to other grease type can cause failure in performance; only soluble oils can be used as additives

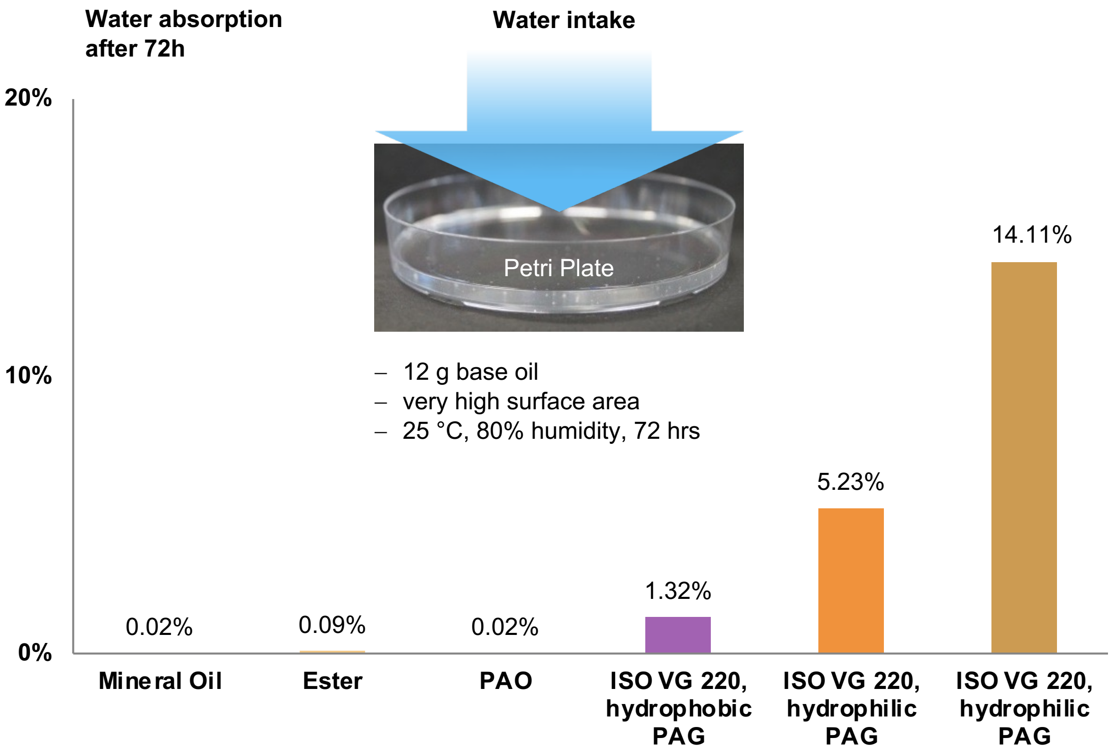
The miscibility of selected PAGs at RT depends on their molecular weight and hydrophobicity

Due to its special architecture, ISO VG 15 is also soluble in some hydrophobic media: low-viscous naphthenic oils, polyol esters and vegetable esters

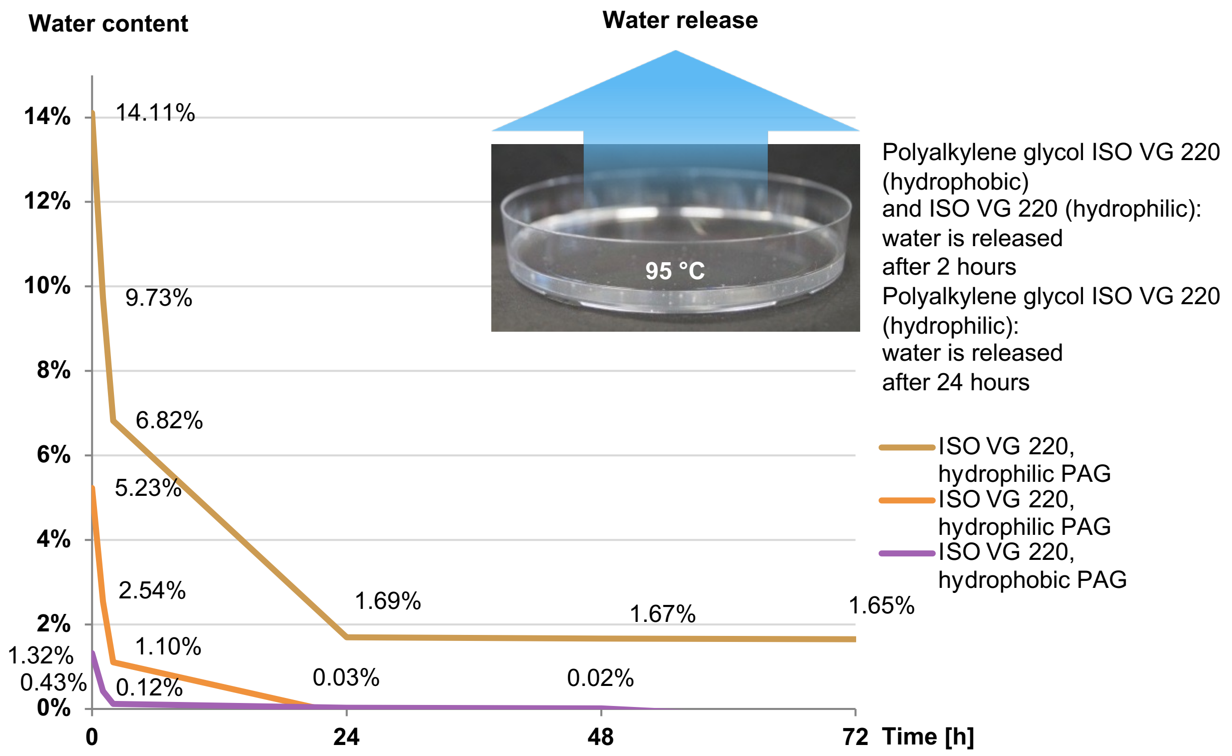
Hydrophilic PAGs
Reversible physisorb water

Polyalkylene glycols absorb water from high humidity environments but tend to release it again

WATER ABSORPTION OF PAGs

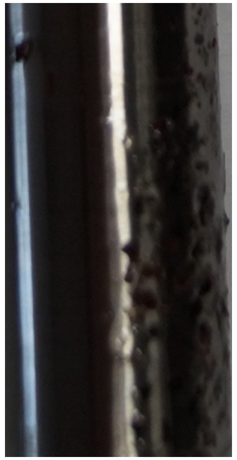
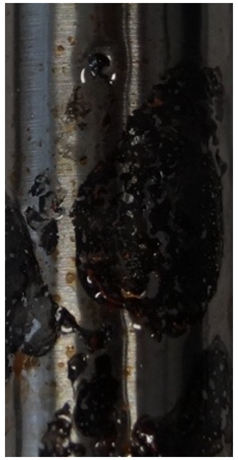


WATER RELEASE OF PAGs



Rust prevention on steel

Rust prevention test (according to DIN ISO 7120 A / ASTM D 665 A):
Cylindrical steel specimen is put in stirred 300 ml oil/10 ml water mixture at 60 °C for 24 h

	DISTILLATES (PETROLEUM), HYDROTREATED HEAVY NAPHTHENIC ISO VG 220	ESTER MIXTURE, BIODEGRADABLE, ISO VG 220	PAO, ISO VG 220	ISO VG 220, Hydrophobic PAG	ISO VG 220, hydrophilic PAG	ISO VG 220, Hydrophilic PAG	MINIMUM REQUIREMENT*
							
Rating	severe rust	moderate rust	moderate rust	moderate rust	**no rust**	**no rust**	no rust
Result	fail	fail	fail	fail	**pass**	**pass**	pass

No rust formation from hydrophilic PAGs on steel without adding corrosion inhibitor

* Minimum requirement according to DIN 51517-3 CLP for gear oils

Formulation 1: Grease based on polyalkylene glycol and soap thickener

- Prepare 10% lithium hydroxide solution by dissolving monohydrated lithium hydroxide in water
- Pour 33% of PAG in GUEDU* mixer at RT
- Add 12-hydroxystearic acid and calcium hydroxide under stirring
- Heat to 75 °C
- At 75 °C, slowly add lithium hydroxide-water solution under stirring
- Heat to 150–155 °C, add remaining PAG
- Heat to 160–165 °C and maintain at this temperature for 1 hour
- After one hour at 163 °C, turn off heat and let formulation cool down under stirring
- At 60 °C, remove formulation from GUEDU mixer and mill using a tricylinder system
- After milling, deaerate formulation in GUEDU mixer under agitation and vacuum

Formula composition

	NLGI 1	NLGI 2	NLGI 3
Ingredient	Content [wt %]		
Polyalkylene glycol ISO VG 15, hydrophilic, modified	88.89	83.54	82.36
Hydrostearic acid	9.84	14.57	15.62
Monohydrated lithium hydroxide	0.80	1.18	1.27
Calcium hydroxide	0.47	0.70	0.75

RT = Room temperature
* Mixer brand

Less softening and wear: Li/Ca polyalkylene glycol grease vs. Li/Ca PAO grease

BENEFITS OF THE PAG-BASED GREASE

- High viscosity index of the oil
- Higher mechanical stability after worked penetration test: Li/Ca PAO grease goes from normal to soft consistency, devolving from NLGI class 2 (265–295) to class 1 (310–340)
- Smaller wear scar

Li/Ca PAO Grease NLGI 2

Li/Ca polyalkylene glycol Grease NLGI 1, 2, 3

	Properties	Method	Li/Ca polyalkylene (PAG) glycol grease Result	Li/Ca Polyalphaolefin (PAO) grease Result
OIL	**Kinematic viscosity** (40 °C) [mm/s^2]	ASTM D 7042	13	19
	Kinematic viscosity (100 °C) [mm/s^2]	ASTM D 7042	3.6	3.8
	Viscosity index	ASTM D 2270	**210**	**127**
	Pour point [°C]	ASTM D 7346-14	-72	-75
GREASE	**NLGI grade**	ASTM D 217	2	2
	Consistency (1/10 mm)	ASTM D 217	**275**	**281**
	Increase		**+5.8%**	**+14.6%**
	Worked penetration – 100,000 strokes (1/10 mm)	ASTM D 217	**291**	**322**
	Drop point [°C]	ASTM D 566	186	190
	Oil separation (168 hours, 40 °C) [%]	ASTM D 1742	-2.3	-6.7
	Wear scar (400 N,1200 rpm,1 hour) [mm] *no temperature control	ASTM D 2266*	**0.54**	**0.73**

Polyalkylene glycol properties compared – Resulting pros and cons

	HYDROPHOBIC PAGs		HYDROPHILIC PAGs		HYDROPHILIC PAG MODIFIED
	Low viscous	**High viscous**	**Low viscous**	**High viscous**	**Low viscous**
PROS	Excellent pour points Water repellent, soluble in hydrophobic media Biodegradable, suited for formulating eco-labeled greases	High thermo-oxidative stability Suited for formulating H1 food-approved greases Water repellent Good lubricity	Biodegradable, suited for formulating eco-labeled greases Excellent pour points	High thermo-oxidative stability Excellent lubricity Biodegradable, suited for formulating eco-labeled greases Suited for formulating H1 food-approved greases	Excellent pour point Miscible both in water and some hydrophobic media High viscosity index relative to molecular weight
CONS	Low thermo-oxidative stability Low lubrication properties Not suited for formulating H1 food-approved greases	Not suited for formulating eco-labeled greases	Low thermo-oxidative stability Tendency for water physisorption Absolutely immiscible with hydrophobic media Not suited for formulating H1 food-approved greases	Tendency for water physisorption Absolutely immiscible with hydrophobic media	Low thermo-oxidative stability Low lubrication properties Not suited for formulating H1 food-approved greases

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Back-up

CLARIANT

what is precious to you?

Fit for food – The Polyalkylene glycols are suited for H1 food grade greases

FDA 21CFR 178.3570[1] lists substances as lubricants with incidental food contact:

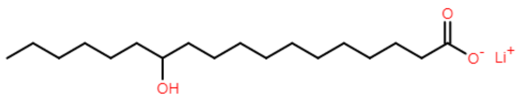
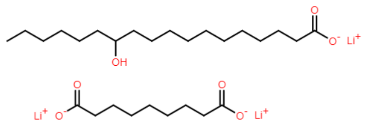
- Restriction for PAGs is a minimum molecular weight of 1,500 (appr. ISO VG 100)
- Addition to food may not exceed 10 parts per million

NSF's white book[2] confirms compliance with 178.3570 as lubricants with incidental food contact (H1) or lubricant ingredient with incidental food contact (HX-1)

Nearly all PAGs with ISO VG 100 or higher are NSF-approved and can be used for H1 food grease formulations

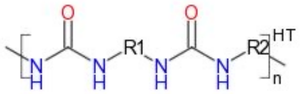
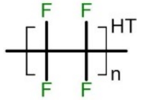
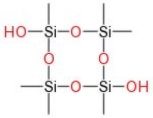
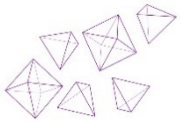
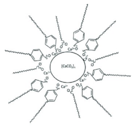
[1] http://www.accessdata.fda.gov/scripts/cdrh/cfdocs/cfcfr/CFRSearch.cfm?fr=178.3570
[2] http://info.nsf.org/usda/psnclistings.asp

Properties of soap thickeners for greases

	SOAP							
	SIMPLE				MIXED	COMPLEX		
Thickener	**Ca**	**Na**	**Li**	**Al**	Mixture of simple soaps	**Ca**	**Li**	**Al**
Chemical structure								
Manufacturing process*	Chemical (typical temperatures ~ 120–160 °C)					Chemical (typical temperature ~ 200 °C)		
Suitable base oils	Mineral oil, PAO, PAG, silicone, esters, vegetable oils					Mineral oil, PAO, PAG, silicone, esters, vegetable oils		
Typical dropping point**	95–105 °C	160–180 °C	175–205 °C	110 °C		≥ 230 °C	≥ 250 °C	≥ 250 °C
Wet conditions	Yes	No	Yes	Medium		Yes	Yes	Yes
Special characteristics	Cost-effective, biodegradable, good water resistance	High dropping points but poor water tolerance	Very good structural properties	Reversible structure if drop point is exceeded		Very good structural properties, water tolerance	Very good walk penetration, good high-temperature characteristics	No hardening at higher temperatures
Cost	Low	Low	High	Medium/high		Medium/high	High	Medium/high
Typical applications	Simple applications and EALs	Electrical applications, gear grease	Multipurpose	Food, special applications, slide bearings, gears		Multipurpose	Multipurpose	Food, steel

Ca = calcium, Na = sodium, Li = lithium, Al = aluminum, PAO = polyalphaolefin, PAG = polyglycol, EALs = environmentally acceptable lubricants
*W. J. Bart et al., Schmierfette: Zusammensetzung, Eigenschaften, Prüfung und Anwendung, Band 500, Expert Verlag, 2000
**High-Temperature Grease Guide (https://www.machinerylubrication.com/Read/340/high-temperature-grease); R. T. Vanderbilt Co.

Properties of non-soap thickeners for greases

	NON-SOAP				
	ORGANIC		**INORGANIC**		**CA SULFONATES**
Thickener	**Polyurea**	**PTFE**	**Silica gel**	**Bentonite**	**Ca sulfonates**
Chemical structure					 (Giasson, et al. (17); Authier and Herman (23)).
Manufacturing process*	Chemical (addition reaction, 180–240 °C)	Physical (RT to < 100 °C)	Physical (RT to < 100 °C)	Physical (RT to < 100 °C)	Chemical (up to 140 °C)
Suitable base oils	Mineral oil, PAO, PAG, silicone, esters, vegetable oils	PFAE	Mineral oil, PAO, PAG, silicone, esters, vegetable oils		
Typical dropping point**	≥ 245 °C	N/A	N/A		≥ 260 °C
Wet conditions	Yes	Yes	Yes	Yes	Yes
Special characteristics	Very high dropping points, excellent mechanical properties but tendency to harden	Superior wear protection for heated roll bearings, chemical inertness	Good oxidation resistance, thermal resistance, chemically inert, flat temperature/consistency-gradient	Not suited for high bearing point velocities, moderate corrosion protection, not compatible with other types of greases	Inherent extreme pressure (EP) properties, excellent salt fog performance, good rust performance
Cost	Very high	Very high	High	Medium/high	High
Typical applications	Bearing grease, low-noise grease, sealed-for-life applications	For chemical inertness	Food, automotive	Food, high-temperature applications	Food, automotive, marine environments

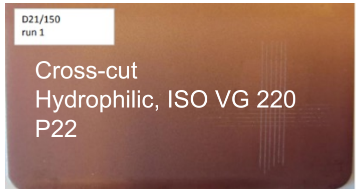
Ca = calcium, PAO = polyalphaolefin, PAG = polyglycol, PFAE = perfluoroalkylether, RT = room temperature
*W. J. Bart et al., Schmierfette: Zusammensetzung, Eigenschaften, Prüfung und Anwendung, Band 500, Expert Verlag, 2000
**High-Temperature Grease Guide (https://www.machinerylubrication.com/Read/340/high-temperature-grease); R. T. Vanderbilt Co.

Compatibility with internal coatings

Flender test (400 g synthetic oil at 130 °C, 7 days; addition of 5% water, 90 °C, 5 hours)

	INTERNAL COATING	BLISTERING DIN EN ISO 4628-2	PENDULUM HARDNESS RATIO DIN EN ISO 1522	CROSS CUT TEST [GT] OIL LOADED AREA DIN EN ISO 2409	
Requirement	M 20, P 22	≤ 1	>0.50	≤ 1	
Product					**FINAL RATING**
Hydrophobic ISO VG 220**	M 20	0*	1.07*	1**	Compatible
	P 22	0*	0.83*	0**	Excellently compatible
Hydrophilic ISO VG 220**	M 20	0*	1.04*	0**	Excellently compatible
	P 22	0*	0.76*	0**	Excellently compatible
Hydrophilic ISO VG 220**	M 20	0*	0.98*	0**	Excellently compatible
	P 22	0*	0.55*	0**	Excellently compatible

PAGs are compatible with Primer M 20 and P 22



Back to material compatibility

* Average of two runs, for every tested oil each single run fulfills requirements, tests were conducted by Mäder Aqualack AG
** Contains additive package

Compatibility with sealings

Elastomer compatibility test (according to DIN ISO 1817, NBR 28/SX, 100 °C, 7 d)

	RELATIVE CHANGE IN VOLUME (ISO 2781)	**CHANGE IN SHORE A HARDNESS (ISO 48, METHOD M)**	**DECREASE IN TENSILE STRENGTH (ISO 37)**	**DECREASE IN ELONGATION AT BREAK (ISO 37)**
Minimum requirement CLP oil	max. 0/+10%	max. -10/+5	max. 30%	max. 40%
Product				
Hydrophobic* ISO VG 220	0.3%	1	5%	19%
Hydrophilic* ISO VG 220	3.9%	-5	5%	10%
Hydrophilic* ISO VG 220	4.3%	-3	0%	10%

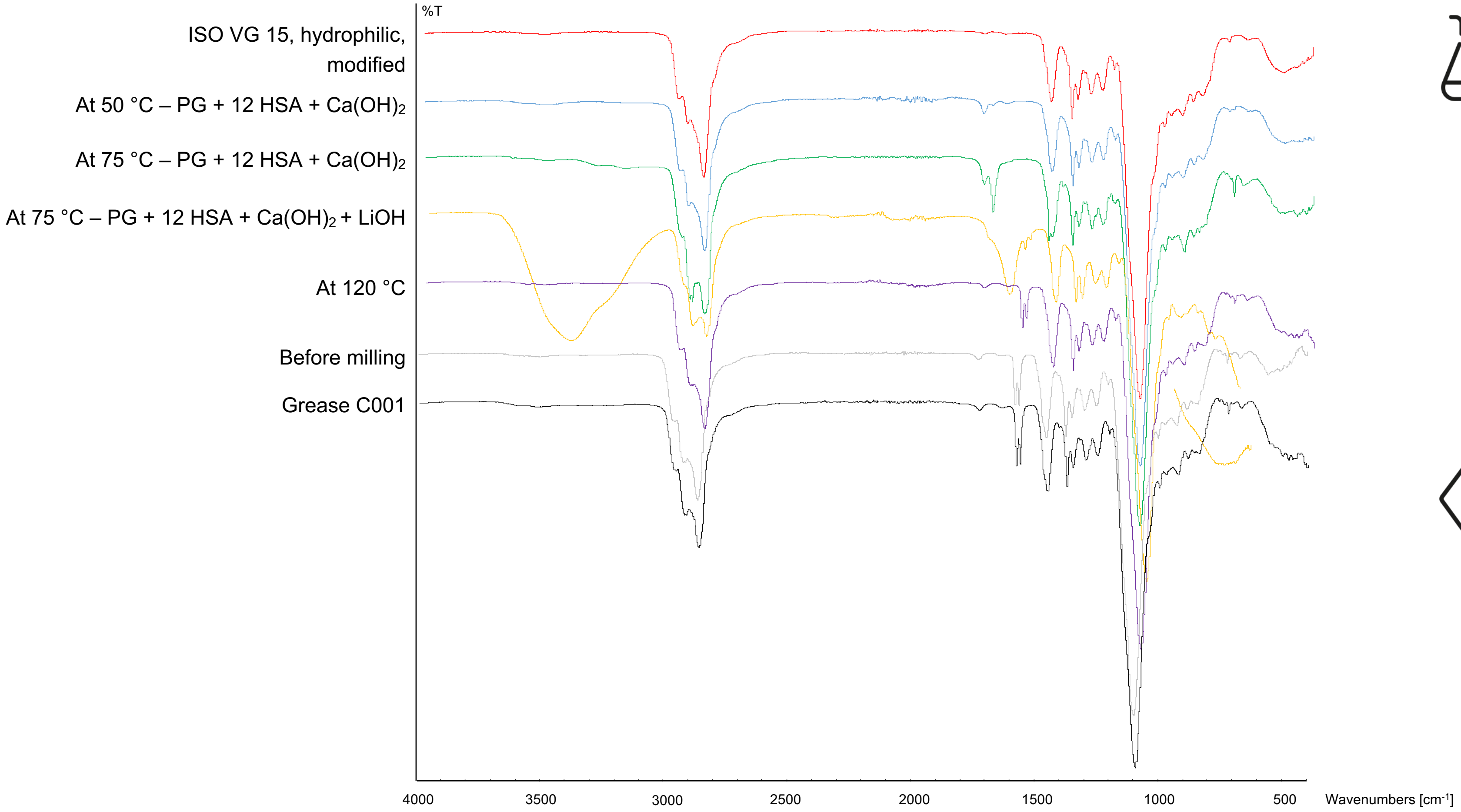
PAGs are compatible with NBR (acrylonitrile butadiene rubber)

Source:
Freudenberg Forschungs-dienste SE & Co KG

Back to material compatibility

* Contains additive package

Grease manufacturing steps monitored via FTIR: Li/Ca mixed grease based on an ISO VG 15 polyalkylene glycol



FTIR spectra are recorded at different steps of manufacturing, starting with the polyalkylene glycol to grease milling and deaeration

The spectra remain the same while the grease is maintained at 160–165 °C, cooled down, milled, and deaerated

No oxidation or transformation of the polyalkylene glycol is noticeable during the process

HSA = hydrostearic acid

Formulation 2: Food-approved grease based on polyalkylene glycol ISO VG 220 (hydrophobic), silica thickener and PTFE as additive

- Pour 50% of ISO VG 220 (hydrophobic) in GUEDU* at RT
- Add silica (and PTFE) under stirring
- When silica (and PTFE) are fully mixed with the oil and no powder is observed, add remaining ISO VG 220 (hydrophobic)
- Stir for 30 minutes
- Remove product from GUEDU and mill using a tricylinder system
- After milling, return product to GUEDU and deaerate under agitation and vacuum

	Formula composition	
	polyalkylene glycol + Silica	**polyalkylene glycol + Silica + PTFE**
Ingredient	Content (wt%)	
ISO VG 220 (hydrophobic)	80.0	75.5
HDK 18 (pyrogenic silica)	20.0	22.0
PTFE	–	2.5

		Formula composition	
		polyalkylene glycol + Silica	**polyalkylene glycol + Silica + PTFE**
Properties	Method	Result	Result
NLGI grade	ASTM D 217	2	2
Consistency (1/10 mm)	ASTM D 217	285	283
Worked penetration – 100,000 strokes (1/10 mm)	ASTM D 217	285	–
Oil separation (168 hours, 40 °C) [%]	ASTM D 1742	0.82	–
Water wash-out (4 g, 600 rpm, 79 °C) [%]	ASTM D 1264	5.1	2.6

RT = Room temperature
* Mixer brand

Selection of base oils for study

BASE OIL	MINERAL OIL	ESTER	POLYALPHAOLEFIN (PAO)	Polyalkylene glycols
Composition	Hydrotreated naphthenic oils: 40% (viscosity 110 mm^2/s) 60% (viscosity 400 mm^2/s)	Biodegradable esters: 66% (viscosity 145 mm^2/s) 33% (viscosity 500 mm^2/s)	17.5% PAO (viscosity 31 mm^2/s) 71% Metallocene PAO (mPAO) (viscosity 614 mm^2/s) 12.5% Alkylated Naphthalene (viscosity 29 mm^2/s)	ISO VG 220 (hydrophobic) ISO VG 220 (hydrophilic) ISO VG 220 (hydrophilic)
Why?	Group III mineral oils are not available at required viscosity	Three esters from different suppliers were tested in terms of lubrication performance Mixture with best lubrication performance was selected	PAO was selected because of its high viscosity index PAO is necessary to adjust viscosity Alkylated naphthalene was added to improve additive solubility	Polyalkylene glycols from existing range were used No formulation work necessary
Viscosity	ISO VG 220	ISO VG 220	ISO VG 220	ISO VG 220