Dr. Nancy McGuire / Contributing Editor

Selecting lubricating greases: What you should know

To get optimal performance and long operating life, pay close attention to specifications and monitor your operations closely.

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KEY CONCEPTS

- Grease formulation is a complex process that takes into account the multiple interactions among base oils, thickeners and additives.
- Solid lubricants physically or chemically adhere to metal surfaces, forming a protective film in the absence of a hydrodynamic lubricant layer.
- Selecting a replacement grease can be a simple matter of matching specifications, but other factors include color, smell and feel or tack.

PEOPLE HAVE BEEN USING LUBRICANTS since ancient times, possibly since the invention of the wheel, to reduce friction and wear between two mating surfaces. A wagon dating back to 1450 BC recovered from the tomb of the Egyptian pharaoh Tutankhamun was found to have lubricant material (probably made from fat and lime) in its wheel hubs.[1]

Lubricants of various sorts have been used continuously since then, but tribology was not defined as a science until British scientist H. Peter Jost published a groundbreaking report in 1966 that quantified the potential economic benefits of systematic efforts to reduce friction and wear. He coined the term *tribology* to mean the study of friction, wear and lubrication. Jost estimated that friction was responsible for energy losses—including heat production and greater fuel costs—costing some £2 billion (£20 billion in today's currency) within the UK alone. He also estimated that proper tribological practices and maintenance procedures could save some 25% of this cost.[2]

MEET THE PRESENTER

Dr. Anoop Kumar

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OIL OR GREASE?

Lubricants can be divided into oils (liquid) and greases (semi-solid). Although greases represent only about 2% by weight of this category (2.48 billion pounds per year worldwide), they provide lubrication in high-pressure, high-load situations where oils are not effective.[3] Worldwide, the demand for lubricating greases has risen from 1.64 billion pounds in 2002 to 2.48 billion pounds in 2015. Much of this rise in demand comes from rapidly developing countries like China, whose grease demand rose from 199 million pounds in 2002 to 884 million pounds in 2015. More mature markets like North America have remained fairly steady in total demand (484 million pounds in 2002 versus 481 million pounds in 2015), but these markets are showing a stronger trend toward high-performance greases than the rest of the world.[4, 5]

Greases are commonly used for bearings, gears, bushings, chain drives and wire ropes (*see Figure 1*). Between 80%-90% of roller bearings are lubricated with greases because grease provides better sealing and load-carrying properties, and it shows a higher resistance to dirt, dust and temperature extremes than oil lubricants can provide. The tradeoff comes in grease's poorer cooling properties (in part because the grease remains in place rather than circulating through the system) and in its viscous resistance (the drag that a grease layer exerts on moving parts).

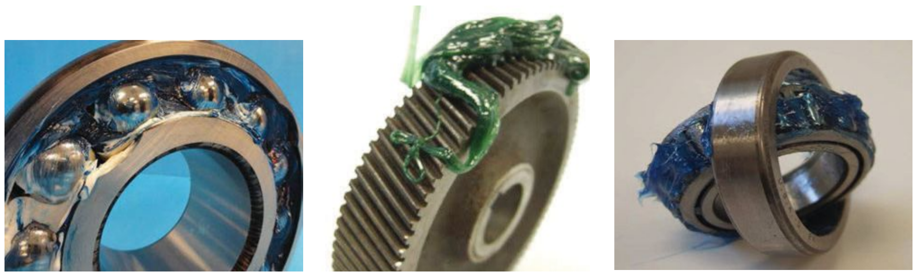

Figure 1 | **Grease on bearings and a gear.** *(Figure courtesy of Royal Mfg Co LP.)*

The dm·N factor (sometimes called the DmN factor) is a useful metric for choosing a bearing lubricant that will perform well under a given set of conditions. This factor is obtained by multiplying the bearing speed in rpms by the average of the outer diameter and bore diameter of the bearing in millimeters.

For a given lubricant viscosity (measured at 40 C, 104 F), a value of dm·N exceeding the corresponding critical viscosity rating indicates that oil, rather than grease, should be used as the lubricant (although some specialty greases can be used for dm·N factors as high as 1 million). Table 1 shows some typical limiting values of dm·N, above which oil is the preferred

Table 1. Grease or Oil?

dm·N factor	ISO viscosity grade (base oil) (40 C)
<100,000	460
100,000	220
300,000	150
500,000	100
600,000	68

lubricant. Typical limiting values of dm·N for various types of bearings are shown in Table 2.[6]

WHAT IS A LUBRICATING GREASE?

Lubricating greases consist of at least 80% base oils, some 10%-15% thickener, with the remainder being additives. However, making a grease is not simply a matter of mixing a set of ingredients together. Grease formulation is a complex process that takes into account the multiple interactions among base oils, thickeners, extreme pressure (EP) additives, anti-wear additives, solid lubricants, antioxidants, tackifiers and friction modifiers. The properties of the final product depend not only on the formulation but also the manufacturing process (including homogenization procedures) and the conditions under which the grease is stored.

Thickeners provide a fibrous matrix that contains the base oil. Under pressure, some of this oil is released into the space between the mating surfaces of the machine parts where it provides lubrication. When the pressure is released, the oil is drawn back into the thickener matrix. At a molecular level, the thickener is attracted to the polar component of the base oil (generally the oxygen atoms in a triglyceride or other oxygenated oil molecule). These attractions take the form of hydrogen bonding, capillary action and van der Waals forces, and they entrap about 75% of oil within the thickener. About a third of the oil in this 75% can be extracted from the thickener matrix by gravity alone. The remaining 20%-25% of the oil is bound within the thickener matrix by mechanical entrapment and

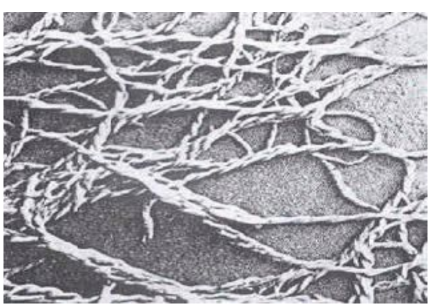

Figure 2 | **Grease matrix micrograph.** *(Figure courtesy of Royal Mfg Co LP.)*

Limiting Values of dm·N Factor

Bearing Type	Alignment	Grease Lubrication*	Oil Lubrication*
Single row radical ball bearing	Ball centered cage	540	720
	Ring centered cage	270	540
Angular contact ball bearing	Ball centered cage	540	720
	Ring centered cage	270	540
Double row self aligning ball bearing		540	720
Thrust ball bearing		180	270
Single-row cylindrical	Roller centered cages	540	720
Roller bearing	Ring centered cages	240	420
Caged needle roller bearing		240	420
Tapered roller bearing		270	350
Spherical roller bearing		270	350
** All values x $(10)^3$*			

Table 2 | *(Courtesy of Royal Mfg Co LP.)*

Lubricating Grease : Trends

Thickener	2015 (%)	2011 (%)	2002 (%)
Aluminum	0.50	0.22	0.20
Aluminum Complex	3.54	3.16	4.66
Calcium	6.82	7.30	9.7
Calcium complex	0.86	0.79	2.07
Calcium Sulfonate	2.83	2.20	0.92
Lithium	54.51	57.36	56.16
Lithium Complex	19.67	18.27	13.86
Sodium	0.38	0.90	1.86
Polyurea	5.90	4.96	4.57
Clay	1.51	1.78	3.04

Soda Base : India 2015 (2.96%) and in 2002 – 9.96 %

Table 3 | *(Courtesy of Royal Mfg Co LP.)*

can only be extracted using solvents or extreme conditions (*see Figure 2*).

Most thickeners are soap based (i.e., they are metal salts or metal complexes with organic fat [glyceride] compounds). Worldwide, about 55% of thickeners are simple lithium soaps, and about 19% are lithium complex soaps. For North America, these figures are 26% and 39%, respectively, and for China they are 63% and 17%, respectively.[5] Other grease thickeners include simple soaps based on calcium, sodium or aluminum; complex soaps based on calcium, aluminum, barium or various sulfonates; and non-soap thickeners based on polyurea compounds and clays. Overall there is a trend toward more high-performing grease thickeners, including complexes and non-soap thickeners.

In recent years, concerns about the long-term availability of lithium, the most commonly used grease thickener, has driven a search for alternatives. The lithium battery industry increasingly competes for the world's supply of lithium, and this has already manifested itself in price increases across the board (*see Table 3*).

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The choice of a thickener has a strong influence on the overall properties of grease. Sulfonates, polyureas and clays are good for high-temperature applications. Aluminum and sulfonate greases are especially water resistant. Barium greases and sulfonates operate well under extreme pressure. Greases thickened with aluminum complexes, clays or soaps made with lithium or calcium are easier to pump than calcium sulfonate or polyurea greases, and they flow more easily through the lines and nozzles of a grease dispenser. They also have better slumpability properties (i.e., they are more easily drawn out of a drum and into a pump). Aluminum complex greases are especially sprayable.

Base oils can be mineral oils (Group I or II paraffins or naphthenic oils), synthetic oils (polyalphaolefins, esters, polyalkaline glycols, silicones and others) or bio-based oils (soybean, rapeseed/canola, castor oil and others). Most greases (some 90%) use mineral oils as the base oil, 6% use synthetic base oils, 3% use semi-synthetics (mixtures of mineral and synthetic oils) and less than 1% use biobased base oils.

The choice of a base oil influences a grease's viscosity and lubricating properties, its susceptibility to oxidation and thermal degradation, its performance at high and low temperatures and how well it flows at low temperatures. In addition, vegetable oils and synthetic esters are biodegradable, which is desirable after the grease has been disposed of but not during operations. Synthetic oils have excellent flow properties at low temperatures.

Additives provide any number of additional properties, depending on the desired performance characteristics. Various additives help a grease perform better under extreme pressures, protect parts from wear, guard against oxidation of the grease, guard against rust and corrosion in the parts it protects and modify friction characteristics. Solid lubricants can be used under extreme conditions. Even though less than 10% of grease consists of additives, they represent a significant part of a formulation's cost.

WHAT DO SOLID LUBRICANTS DO?

Under hydrodynamic conditions, the moving parts are fully separated by a liquid lubricating oil film, which minimizes friction between those parts. However, under boundary/elastohydrodynamic lubrication conditions typical of heavy loads and high pressures (for example, in mining or off-highway applications), asperities on the mating surfaces will break through an oil lubricant film and come into direct contact. These asperities can cold weld together under pressure—causing pitting and wear—and creating sites where corrosion can occur. In these situations, solid or semi-solid (grease) lubricants with antiwear additives are required.

Solid lubricants physically or chemically adhere to metal surfaces, forming a protective film in the absence of a hydrodynamic lubricant layer. This protective film reduces friction and prevents welding. Solid lubricants can be layered materials like graphite or molybdenum disulfide (MoS_2). Each layer of these crystalline materials is one atom thick with layers stacked like a deck of playing cards. Individual layers slide past each other easily, providing a lubricant action, but the layers resist compression when force is applied perpendicular to the layers.

HIGH-PERFORMANCE REQUIREMENTS

General-purpose greases, including lithium 12 based (containing Li-12-hydroxystearate, a common grease thickener), calcium based and sodium based, are suitable for application temperatures below 250 F (121 C) and parts under mild loads. The presence and effectiveness of EP additives are rated using standard tests, which produce ratings like a Timken OK load or weld load. General-purpose greases generally have a 40-45-pound Timken rating and about a 250-kilogram weld load.

A high-performance grease may be required when operating conditions include very high or very low temperatures, heavy loads or shock loading, very high or very low motor speeds or environments in which the grease is exposed to water, dust or dirt. High-performance greases include lithium or aluminum complexes, calcium sulfonates, polyureas and clay-based greases.

High-performance greases can operate at temperatures as low as -54 F (-48 C) or as high as 450 F (232 C), and they contain EP additives that stand up under heavy loads or shock loading. These greases exhibit less than 5% washout and less than 30% spray off when exposed to water. They continue to provide lubrication at speeds exceeding 1,400 rpm.

SELECTING A GREASE

Users can follow one or more approaches to selecting the best grease for a particular operation. Often, OEMs will provide specifications. Industry organizations like the National Lubricating Grease Institute (NLGI) also provide guidance. For example, the NLGI certifies automotive chassis greases (LA and LB) and wheel bearing greases (GA, GB and GC), with a GC-LB designation representing the highest performance classification.

If a grease currently in use is working well, selecting a replacement grease can be a simple matter of matching specifications. New products can be evaluated and analyzed for suitability before putting them to use in the field, or new greases can be used in field trials and tested in actual applications.

Other factors influencing grease selection include color (greases come in a wide range of colors, some of them very bright), smell and feel or tack. In a survey of customer complaints in 2015, only 14% dealt with failure in actual test properties. Of the total number of complaints, 42% were in connection with grease color, 20% dealt with consistency, 16% with tack or texture and 8% with smell.[7]

Of course, a grease with the right color and smell is of very little help if it doesn't also hold up well in its intended application. Thus, selecting a lubricating grease will depend on the size of a bearing or gear, the operating temperature range, motor speeds, maximum loads (steady or shock), the

The world's smallest spider is the *Patu marplesi*. Ten of them could fit on the end of a pencil.

amount of water or moisture ingress expected and the amount of dust and dirt in the environment. Merely selecting a grease with the maximum rating in each category can be cost prohibitive and may not give you your desired results; it's better to aim for the optimum set of properties.

Grease suppliers provide technical data sheets (TDS) to help in matching a grease formulation with specific parts and operating conditions (*see Table 4 for an example*). Ratings include mechanical and shear stability: the resistance of the grease to dripping out from between the mating surfaces. Water resistance is given as ratings for water washout, water spray off and mechanical roll stability. Weld load and Timken OK load ratings indicate EP additive presence and effectiveness. Drop point and high-temperature life indicate a grease's performance at high temperatures. Low-temperature characteristics include low-temperature torque (LTT), pumpability, shear rate and flow (measured using a Lincoln ventmeter) and U.S. Steel mobility test ratings. Tables 5-7 illustrate the wide variety of grease properties and how they relate to various applications.

Selecting Lubricating Grease Based on TDS

Property	Test Method	Industrial Grease
Thickener Type	-	Calcium sulfonate Complex
Appearance	Visual	Smooth
Color	Visual	Green
NLGI Grade	NLGI	2.5
Worked Penetration	ASTM D-217	250-280
Drop Point , F	ASTM D 2265	+ 550
Base oil viscosity, cSt at 40^{0}C	ASTM D-445	178
Wheel bearing leakage, gm	ASTM D-1263	5.0 Max
Rust Test	ASTM D 1743	Pass
Water washout @ 175 F , % wt	ASTM D-1264	3.0
Weld load, kg	ASTM D 2596	620
Load Wear Index	ASTM D 2596	65
Timken OK Load, lb	ASTM D-2509	65
USS Mobility Test	USS DM 43	
@ 0 ^{0}F, gm/min		13.6
@ - 20 ^{0}F , gm/min		4.0

Challenge : Is this grease suitable for my application?

Table 4 | *(Courtesy of Royal Mfg Co LP.)*

Comparative Property Attributes of Some High Performance Greases

Property	Technical Verbiage	Li-MP	Li-Com	Ca-sulfonate	Al-com	Clay Base
Stability	Mechanical Stability	XXXX	XXXX	XXXXX	XXX	XXXX
	Roll Stability	XXXX	XXXX	XXXXX	XXX	XXX
High Temp.	Drop Point	XX	XXX	XXXXX	XXX	XXXXX
	High Temp. Life	XX	XXX	XXXX	XXX	XXXX
Water Resistance	Water Washout	XXX	XXX	XXXXX	XXXXX	XXX
	Water Spray Off	XX	XX	XXXXX	XXXX	XXX
	Roll st. In presence of water	XX	XXX	XXXXX	XXXX	XX
Extreme Pressure	Weld Load	XX	XXX	XXXXX	XXX	XX
	Timken	XX	XXX	XXXXX	XX	XX
	Wear Scar Dia	XXX	XXX	XXXX	XXXX	XXX
Compatibility with lithium greases			V. GOOD	GOOD	POOR	POOR

More XXXXX : Better **Lithium complex and Calcium sulfonate greases are favorite**

Table 5 | *(Courtesy of Royal Mfg Co LP.)*

DIFFERENT INDUSTRIES, DIFFERENT GREASES

Various industries show preferences for different types of greases. For example, the mining and construction industries used calcium and calcium complex greases in the past, but they are now moving toward calcium sulfonate complex greases. Lithium and lithium complex multipurpose (MP) greases and aluminum complex greases also are commonly used. Because much of the work in these applications occurs outdoors, these industries are showing greater interest in biodegradable and environmentally friendly products.

Marine applications use a variety of calcium or lithium MP greases. Calcium sulfonate greases also are used because they hold up better under salt spray. Marine industries also are moving toward greases that are biodegradable and that comply with Vessel General Permit regulations. The agriculture and forestry industries use lithium MP greases, and they are moving toward vegetable-sourced (ester) base oils for their biodegradability properties. Food industry applications must comply with their own set of strict regulations, and they tend toward calcium, clay and silica greases. They also may use aluminum complex and calcium sulfonate greases.

Open-gear applications relied on asphaltic-based products in the past. Now aluminum complex-based greases are preferred over other types. Constant-velocity joints may use lithium and lithium complex greases with molybdenum sulfide or graphite EP additives, or, preferably, they may use polyurea greases.

USEFUL TIPS

Getting the best performance and longest operating life out of a grease requires careful attention to the specifica-

General Recommendations

Lithium soap with suitable oil-viscosity and additives	Operating temperature up to 250 ^{0}F max	• Multi purpose • Automotive chassis and wheel bearings • Non-critical Industrial
Li-complex soap with suitable oil – viscosity and additives	Operating temperature up to 300-350 ^{0}F max	• High temperatures • High pressure and shock load
Aluminum complex soap with suitable oil – viscosity and additives	Operating temperature up to 300-350 ^{0}F max	• Heavy water environments • High temperatures • Food processing industry • Mining operations
Poly urea with suitable oil-viscosity and additives	Operating temperature up to 300-400 ^{0}F max	• High Temperatures • Oven, conveyor bearings, electric bearing
Clay	Operating temperature up to 300-325 ^{0}F	• High temperatures • Food processing
Sulfonate Greases with suitable oil viscosity and additives	Operating temperature up to 300-350 ^{0}F	• Water prone • Mining and Marine • High Temperatures

Table 6 | *(Courtesy of Royal Mfg Co LP.)*

General Recommendations

Environment	Industry	Recommendation
Moderate Load, Temp (0 ^{0}F to + 250 ^{0}F), High Speed, less water ingress	Agriculture , Farm, Truck & Auto WB , General purpose	Lithium EP (VG 150-220 oil; NLGI 2)
Heavy Load, Temp (0 ^{0}F to + 300 ^{0}F) , Moderate Speed, some water ingress	Agriculture, mining Construction , Farm, Truck & Auto (GC-LB), Heavy Duty	Lith. Complex EP (VG 150-220 oil; NLGI 2)
Extreme Load, Temp (0 ^{0}F to + 300 ^{0}F), Low Speed, humid and Dusty Environment	Agriculture / Farm, Off Highway, Mining, Heavy Industry	Lithium Complex EP Greases (VG 460 ; NLGI 2) or Sulfonate Complex
High Speed , Moderate Load, Temp (- 40 ^{0}F to + 350 ^{0}F), Moderate water	Agriculture / Farm, Off Highway, Mining, Heavy Industry	Synthetic Greases (Lithium Complex, Polyurea, Sulfonate Complex)
Incidental Food Contact , Hot & Cold Temp , High speeds , Moderate loads	Food & Beverage Industry	H1 Food Grade Greases (Aluminum Complex)
Incidental Food Contact , Very Hot (0 ^{0}F to + 300 ^{0}F), Moderate Speed, Extreme Heavy Loads , lot of Water	Food & Beverage Industry	H1 Food Grade Greases (Calcium Sulfonate / Syn FG grease)
Extreme Load, High Temp (0 ^{0}F to + 300 ^{0}F) , Low Speed , Plenty water and Dusty Environment	Steel, Mining, Paper Mill, Power Generation, other Heavy Industry	Aluminum Complex and Sulfonate Complex

Table 7 | *(Courtesy of Royal Mfg Co LP.)*

tions and monitoring your operations to make sure you stay within those specifications. For instance, the life of your grease decreases by half for every 10 degrees that you exceed the recommended operating temperature. For general-purpose greases, the application temperature should be kept below 250 F (121 C). For high-performance greases, mineral-type base oils can go up to about 350 F (177 C), and synthetic base oils can go as high as 450 F (232 C).

Oil bleed (the amount of oil that comes out of a grease during storage) should not exceed 5%, and keeping this to about 1%-2% is preferable for good lubrication. You don't have to fill the whole housing to get good lubrication: for medium to high speeds, about 50% is optimum, with more than 50% required for higher speeds.

If the grease will be in contact with other types of lubricants, check for compatibility issues. This is especially important for synthetics.

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REFERENCES

1. Lorenzi, R. (Aug. 3, 2010), "King Tut's chariots were like Formula One cars," *Discovery News*. Available at **www.nbcnews.com/id/38545625/ns/technology_and_science-science/t/king-tuts-chariots-were-formula-one-cars/#.WTq5xBPyuFO**.
2. Wood, R. J.K and Harrison, K. (June 9, 2016), "Dr. Peter Jost CBE 1921-2016, *UK Tribology Network*. Available at **www.uktribology.net/news/dr-peter-jost-cbe-1921-2016**.
3. Lubes'N'Greases 2015 Lube Report. Available at **https://pubs.lubesngreases.com/lubereport/**, subscription required.
4. NLGI 2002 Grease Production Survey Report.
5. NLGI 2015 Grease Production Survey Report. Available at **www.nlgi.org**, subscription required.
6. Prasar, R.K. (2004), "Lubrication Simplified," p. 108. ASIN: B00LTU109K.
7. Kumar, A., Bhatnagar, N. and Mallory, B. (May/June 2017), *NLGI Spokesman*, 81 (2), pp. 12-17. Available at **https://issuu.com/kim0824/docs/nlgi_spokesman_may_june_2017**.

 Jumping spiders can leap up to 40 times their own body length. If humans could jump this far, they would be able to jump over 230 feet.