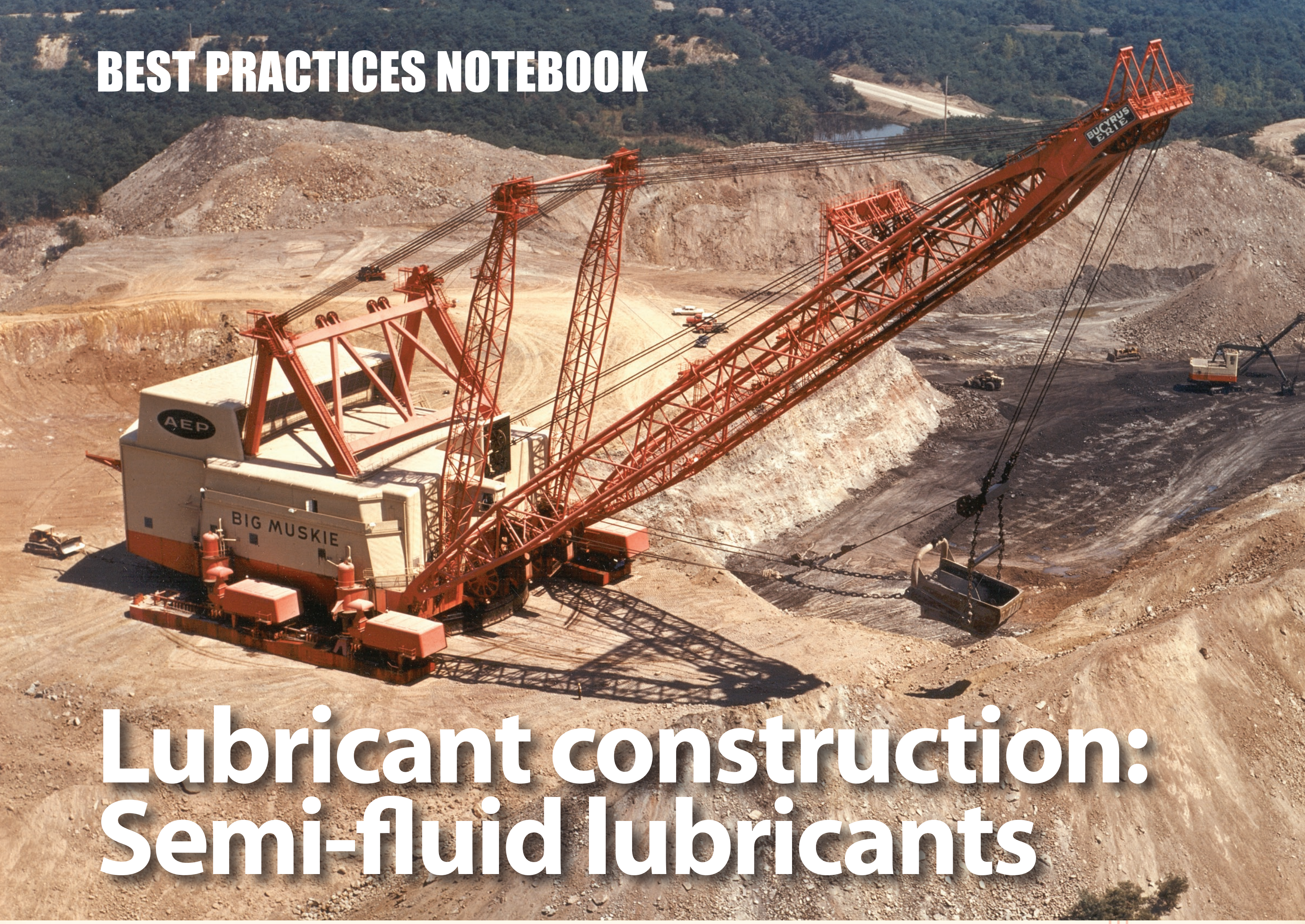

Lubricant construction: Semi-fluid lubricants

These unique lubricants come in a variety of types and are most commonly found in mining, mineral processing and milling applications.

Article highlights:

- The six common types of semi-fluid lubricants.
- AGMA standards play an important role in the marketplace.
- Applications found in semi-fluid greases are thickeners.
- Selection and application can vary according to different products.

The May and June Best Practices Notebook introduced information about the composition of fluid and grease lubricants, the nature of lubricant raw materials used in those products and how the materials protect machine surfaces from wear and degradation. This month we'll look at another lubricant category that exists between these two well-recognized lubricant products—semi-fluid lubricants.

In this article, semi-fluid lubricants (i.e., semi-fluid grease) will be addressed first as a prelude to addressing the topic of lubricant selection for open gears, low-speed enclosed gears and bushings and machines with cases experiencing severe leakage.

Types and applications

Semi-fluid lubricants exist in a variety of con-

Thickeners used for other grease-type products, lithium and aluminum complexes are common for semi-fluid greases.

figurations, each having a designed function and end-use. By their very nature these lubricants are designed to serve the reliability and machine protection requirements of heavily loaded and low-speed machines. The dominant applications driving technological development for this class of lubricants has been, and will continue to be, large mining and mineral processing/milling applications, including gears, bushing and element bearings.

Semi-fluid lubricants could fall into one of six different categories:

1. Asphaltic oils or black oils.
2. Asphaltic cutbacks.
3. Semi-fluid greases.
4. Semi-fluid grease cutbacks.
5. Polymerized lubricant gels.
6. High viscosity synthetics.

An argument could be made to characterize the first, second and last options as fluid lubricants, given that no thickener is used to stiffen the material for application, but they remain in the semi-fluid category because these are often barely fluid at room temperature and because of the common types of applications for which these lubricants are constructed.

Asphaltics & Asphaltic cutbacks

Asphaltic lubricants are referred to as black oils or bituminous oils. They are made from the tacky tar-like substances left over from the vacuum distillation portion of the solvent refining of petroleum. Asphaltic materials also occur naturally in the form of asphalt lakes (incorrectly called tar pits such as the La Brea Tar Pits in Los Angeles) or oil sands. These non-volatile oil stocks can be characterized by their high molecular weight structures (hydrocarbons in excess of 25 carbon atoms and a high ratio of hydrogen atoms) and slight amounts of sulfur, nitrogen and trace metals. They are brown or black in color and are nearly solid at room temperature.

The original application of asphaltic materials occurred through the mixture of high viscosity asphaltene (poly-aromatic molecule structures) with lower viscosity lubricating oils to create highly viscous and tacky lubricating oils for large, slow moving pins, linkage, bearings and other components. This type of lubricant was resistant to wash-off, could support high loads and shock loads and was inexpensive to produce. The low cost made it attractive for total loss application requirements.

The highest concentration of applications for asphaltic products occurs in mining and milling applications. Many of these machine applications operate through the use of large semi-enclosed gears, bushings, bearings and steel cables. In the early development of these machines, operators required products that could be hand-applied, since automatic lubricant application devices weren't common, and would be very tacky (adhesive) toward the machine surfaces to allow for long periods between relubrication intervals. Because the products were created from raw materials that were solid or nearly solid at room temperature, the lubricants had to be heated to make them flow and were applied hot.

When they cooled following contact with the machine surfaces, they returned to a very tenacious, viscous, tacky state to accomplish the job of surface protection. As additives developed they were added to the finished products to afford even better protection. These product types were staples for mining and mineral processing equipment operators for decades.

Progressively automatic application systems became more popular in the mining and milling applications because they reduced the risk that components (gears in particular) would run dry or go too long between relubrication cycles. Heated asphaltic products created problems with the use of automatic systems because they tended to cool down and plug the lubricant feed lines and nozzles. To improve lubricant pumpability the industry began integrating solvents into the asphaltic materials. By the late 1970s to early 1980s, operators of large mills and mining machines had largely adopted asphaltic oils that were cut with nonflammable solvents to make them fluid at room temperature, which greatly enhanced their relative ease of application.

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Throughout this period of development, OEMs and industry standards changed to reflect different types of products introduced to the market. The American Gear Manufacturers Association (AGMA) formed a committee to produce a standard as early as 1938, with the formal adoption of the first industry standard for enclosed and open gearing in 1946. The standard has been annotated and revised a number of times through the years, leading to the

Table 1. AGMA 9005-E02 Standard - Table D-1 Minimum Viscosity Recommendation for Continuously Lubricated Open Gears

AGMA 9005-E02 Standard - Table D-1
Minimum Viscosity Recommendation for Continuously Lubricated Open Gears (1)

Ambient Temp., °C	Type of operation	Splash Lubrication, Pitch Line Velocity (2)		Pressure fed Lubrication, Pitch Line Velocity (2)		Idler Emmersion, Pitch Line Velocity (2)
		v_t < 5 m/s	v_t > 5 m/s	v_t < 5 m/s	v_t > 5 m/s	v_t <= 1.5 m/s
-10 °C to +10 °C	Continuous	220	150	220	150	680 - 1500
	Reversing or start-stop	460	320	220	150	680 - 1500
+10 °C to +30 °C	Continuous	460	320	460	320	1500 - 2200
	Reversing or start-stop	1500	680 - 1000	460	320	1500 - 2200
+30 °C to +50 °C	Continuous	2200	1500	460	320	4600
	Reversing or start-stop	2200	1500	460	320	4600

Notes:
(1.) All viscosities shown are in mm^2/s @ 40°C.
(2.) Pitch Line Velocity = (Pitch Diameter in millimeters X RPM) ÷ 19098 = meters/second.

Table 3. NLGI Standard Grease Stiffness Referer

NLGI Grades	Consistency Similar To	Worked Penetration 60 Strokes @ 25° C
000	Thick Cream	445 – 475
00	Tomato Sauce	400 – 430
0	Mustard	355 – 385
1		310 - 340
2	Tomato Paste	265 - 295
3		220 - 250
4	Soft Cheese	175 - 205
5	Hard Cheese	130 - 160
6	Block of Wax	85 - 115

Table 2. AGMA 9005-E02 Standard - Table D-2 Minimum Viscosity Recommendation for Intermittently Lubricated Open Gears (v_t < 7.5 m/s)

AGMA 9005-E02 Standard - Table D-2
Minimum Viscosity Recommendation for Intermittently Lubricated Open Gears (v_t < 7.5 m/s)

Ambient Temp., °C	Intermittant Spray: Non-Residual Lubricant	Intermittant Spray: Residual Lubricant	Gravity Feed or Forced Drip
-10 °C to +5 °C	4140 cSt @ 40°C (1)	428 cSt @ 100°C (4)	4140 cSt @ 40°C (1)
+5 °C to +20 °C	6120 cSt @ 40°C (2)	856 cSt @ 100°C (5)	6120 cSt @ 40°C (2)
+20 °C to +50 °C	190 cSt @ 100°C (3)	857 cSt @ 100°C (6)	190 cSt @ 100°C (3)

Notes: (1.) Formerly AGMA 11EP and 11S. (2.) Formerly AGMA 12EP and 12S. (3.) Formerly AGMA 13EP and 13S (14.) Formerly AGMA 14R. (15.) Formerly AGMA 15R.

current standard, AGMA 9005-E02. In the standing version, AGMA has provided tables (D-1 and D-2) that correlate to gear speed and ambient temperature to different modes of application, from continuous (bath or idler application) to intermittent spray and gravity-drip application methods (*See Tables 1 and 2*).

The ideal solvent for the application, 1,1,1-trichloroethane, ultimately was found to be an environmental hazard and was targeted for elimination by the EPA. This imposed change opened the door for development of new alternatives.

Semi-fluid greases & grease pastes

Semi-fluid greases had been in production and use in Europe for roughly 40 years by the time the Montreal Protocol ban on chlorinated solvents went into effect in 1995. Although not common in North America, these products had demonstrated that a reliable alternative, particularly for the primary application open gears could be developed. Semi-fluid greases contain medium to high viscosity base oils, either polymerized mineral oils or synthetic base oils, wear-resistance solid film additives and EP agents, rust inhibitors and a thickener. Thickeners used for other grease type products, lithium and aluminum complexes are common for semi-fluid greases. Because a thickener is in use, even though these are a relatively low consistency NLGI No. 0 to NLGI No. 1 grades, these are sometimes referred to as grease pastes. An NLGI table is provided with a general stiffness correlation to common products, as shown in Table 3.

This approach provides owners of complex draglines and shovel type mining machines with an opportunity to greatly reduce the number and variety of lubricants required for a given machine and, ultimately, for an entire fleet. Draglines and mechanical mining shovels have multiple types of heavily loaded and slowly turning components that can be serviced by a single medium- to high-viscosity grade product. Also, the lubricant often can be applied without substantial changes to existing application equipment, and when applied properly the product takes on a semi-dry film that both remains in place and doesn't attract and hold high concentrations of airborne solids. These products are typically consumed in higher volumes, though, and at a higher purchase cost than the predecessor asphaltic type products.

Semi-fluid grease cutbacks

Grease cutbacks are similar versions of the semi-fluid greases that incorporate the use of thinning solvents to improve pumpability for use in very low temperature applications. Severely low temperatures (< 0 F) create grease-pumping challenges for even a few feet of exposed machine and piping. Once the solvent has dissipated, the grease establishes a pliable and tenacious layer of grease to protect components.

Polymerized lubricant gels

Lubricating gels are similar in nature to semi-fluid greases. Both types contain medium- to high-viscosity mineral and synthetic basestocks and both incorporate the use of lubricating solids and EP agents. Lubricating gels also carry NLGI ratings slightly lower than that of the semi-fluid greases and may also contain a solvent.

Compared to their soap-thickened counterparts, these lubricants are stable over a longer period of time, experience less tendency to separate from the thickener due to shear stress or temperature stress and at the same time demonstrate shear-thinning attributes that lowers overall frictional characteristics.*

High-viscosity (HV) synthetics can meet or exceed the AGMA 14R (428.5 cSt @ 100 C) and 15R (857 cSt @ 100 C) viscosity requirements, even though they are not cutback-type lubricants.

Application rates can differ appreciably between high-viscosity gels, semi-fluid grease and solvent cutback type asphaltic residuals. The previously noted AGMA standard provides specific guidance for cutback lubricant volumes and intervals, but the application of gels and greases can be dramatically different, both in terms of frequency and volume, based on the materials used and the nature of the surface protecting film. Under the right circumstances the high-viscosity gels may allow for net feed volumes well below the AGMA baseline values (decreased volumes per application with increased frequency of application).

High-viscosity synthetic oils

This last category is included for consideration as a semi-fluid mostly because it is a current technology for the same types of applications that have been presented in this article. High- viscosity (HV) synthetics can meet or exceed the AGMA 14R (428.5 cSt @ 100 C) and 15R (857 cSt @ 100 C) viscosity requirements, even though they are not cutback-type lubricants. This is brand- and product-type specific. HV synthetics are polyalphaolefin and ester base oil blends and are formulated with wear and seizure-resistance additives and corrosion inhibitors. Since they don't contain thickeners of any type, they are not subject to shear stability and oil separation that grease paste-type lubricants are subject to in similar applications.

Selection and application

Semi-fluid lubricants represent a wide variety of lubricant types and compositions. While a general statement about their intended use in heavily loaded and slowly operating machines is defendable, the selection and application for the products types can and should vary significantly. The actual use cost for these specialized products is often quite different than the perceived cost-based application technique and unit purchase price. With poor application effectiveness, it is not uncommon for the lower unit cost products to actually produce higher use cost results.

There are many different suppliers of these types of products whom generally can provide some key point of benefit for their respective product if used according to instructions. The reliability engineer should pay very close attention to the technique for application and should enlist any candidate supplier to work closely thorough a trial application period to assure that the product has every opportunity to fulfill its stated performance objective. Slight variations in application may mean a substantial difference in the net performance and promised economic benefit.

Conclusion

Semi-fluid lubricants come in a wide variety of types and meet an equally wide variety of uses. These products have changed significantly since the prototypes were constructed.

Environmental regulations have pushed manufacturers of these types of products progressively away from the use of solvent-thinned asphaltic hydrocarbons toward more sophisticated high-viscosity synthetic and polymerized mineral oils, with a variety of thickener system types.

Application technique is particularly important to achieve the economic potential that a more sophisticated product represents. TLT

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* Samman, N. and Lau, S.N. (1999), "Grease-Based Open Gear Lubricants: Multi Service Product Development and Evaluation," *Lubrication Engineering*, **55** (4) pp.40-48.