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Biodegradable Open Gear Lubricant

By

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ABSTRACT

Open gear lubricants are subject to particularly difficult operating conditions. Thus, not only must the lubricant perform functions of minimizing friction and wear, but it must also withstand the pressure, temperature, and operating conditions, found in difficult environments. Mineral base greases have been the lubricant of choice for a long period of time. Recent years have seen a growth in interest in the provision of environmentally friendly lubricants. This is particularly true for systems where the lubricant may be lost after use or accidentally come in contact with the environment. A biodegradable open gear lubricant has been developed to address these new challenges. Laboratory results as well as the field testing data demonstrate the equivalency, if not the supremacy of the biodegradable compound over the petroleum base lubricant over a wide range of operating conditions.

Introduction

Open gear lubricants are subject to difficult operating conditions. Thus, not only must the lubricant perform its basic function of reducing friction and preventing metal-to-metal contact between moving surfaces, but it must also withstand the pressure, temperature and operating conditions found in difficult environments. In mining operations for example, the machinery is exposed to an atmosphere of solid contaminants such as dust and minerals, to moisture in the form of humidity, rain and/or snow. Mineral base greases have been the lubricant of choice for a long period of time. Recent years have seen a growth in interest in the provision of environmentally friendly lubricants. This is particularly true for systems where the lubricant may be lost after use or accidentally come in contact with the environment. A biodegradable open gear lubricant has been developed to address these new challenges. Laboratory test results will be presented along with the field testing data side by side with those obtained on a conventional mineral based open gear compound [1].

Basic Requirements for Open Gears

- Tackiness and adhesion: the protecting film must strongly adhere to the surface to be lubricated without peeling or excessive throw-off;
- Extreme pressure resistance: should withstand heavy loads and shock loading;
- Heat resistance: should not flow or harden in service and should not run even if applied on vertical surfaces;
- Water resistance: should withstand water spray off;
- Mechanical shear stability: should not significantly change its consistency in service;
- Dust resistance: should be able to withstand to some extent entrapment of intense amounts of dust without losing the basic lubricating properties;

- Pumpability: the product must be pumpable, dispensable and mobile at operating temperatures;
- Reversibility: should be stable under repeated hot and cold cycling

Regulatory issues

There are some laws and regulations in some of the European countries that mandate the use of bio-based or low toxicity biodegradable lubricants. In the US, there are no such laws. There are however incentives encouraging the use of such products if they can contribute to address a regulatory compliance issue [2].

Biodegradable Base Oils

In recent years, the awareness over the utilization of mineral based oils and their effect on the surrounding media has created the opportunity to produce environmentally friendly lubricants from agricultural products. These products have the advantages of being less volatile, having minimal health and safety risks and being easy to be disposed of due to their inherent biodegradability. Several biodegradable precursors such as esters and vegetable oils have been proposed for use in lubricants. Thus, such lubricants discussed in [3, 4, 5, 6, 7, 8] references suggest that the bio-based products could represent a potential feedstock that may provide an acceptable cost-performance balance without carrying any risk to the safety, health and environment.

Biodegradable Open Gear Compound

The provision of a biodegradable lubricant, which is suitable for open gear applications with their severe performance requirements, has proven to be a difficult problem.
The present project seeks to provide acceptable open gear lubricants, which perform at least as well as conventional mineral oil based products under a range of operating conditions.

Formulation

A combination of vegetable oils, thickening systems, solid compounds and a package of functional additives constituted the formula of the finished product that has been subjected to laboratory and field testing. The product has been homogenized through a stone mill improving the grease consistency and eventually its stability over time.

Laboratory Testing

Smoothness/Film Adhesion and Strength
This visual testing, applied to open gear products, allows one to qualitatively evaluate the product smoothness and the film adhesion and strength. A small sample is applied on a smooth surface of an aluminum top bench. It is spread, first in a thick film to

check the product smoothness, and after that, by means of a spatula, in a very thin layer, to check for the film adhesion and strength.

Pumpability

The product pumpability is determined by the Modified Lincoln Ventmeter Test method [9]. The grease is charged by the means of a lever gun into a standardized coil and then placed into a cooling bath in which a thermometer is immersed. A stirrer is placed in the bath to ensure temperature homogenization. The grease is compressed with the lever gun until a pressure of 1800 PSI is attained. The batch cooling is set and maintained in service until the desired temperature is obtained. During the cooling step, the pressure is kept at 1800 PSI by using the lever gun. After 15 minutes of thermostating at the testing temperature, the system is depressurized. The pumpability is measured as the pressure read 30 seconds after valve release.

Thermal Retention

This test evaluates the ability of grease to adhere to metal surfaces when subjected to high temperatures. The procedure consists of applying a small amount of product (0.5-0.6 grams) on a clean surface of a steel plate. The plate is placed in a vertical position in an oven set at the testing temperature. After 30 minutes, the steel plate is removed and the trace of the sliding product is measured. The length of the sliding path, in centimeters, is a measure of the thermal retention.

Reversibility

The reversibility test evaluates the ability of grease to conserve its original properties when exposed to extreme temperatures (high and low) and to sunlight radiation. The unworked and worked penetrations, as described by ASTM D 1403, are used to determine the changes in consistency. Three samples are experimented:

(1) First sample kept for 7 days at 75°C in the oven and, after that, 1 day at room temperature.
(2) Second sample kept during 7 days at 0°C in a refrigerator and 1 day at room temperature.
(3) Third sample (glass jar) exposed during 8 light days at sunlight radiation and at a temperature during the day fluctuating between 38 and 42°C.

Dust Resistance

This test evaluates the capacity of grease to hold mining dust, without losing the gel-like appearance. The dust sample is provided by an iron mining site in the USA. The test consists of progressively adding different amounts of dust to a determined quantity of a grease, mixing intimately the dust with the grease by means of a spatula, and visually checking the aspect of the grease as a thick layer, and as a thin film. The test is terminated when a grainy paste is obtained and the applied film shows a tendency to peel off.

Water Resistance
This test evaluates the ability of a grease to withstand the water wash off due to rain, snow or high humidity. ASTM D 4049 allows the quantification of the grease loss under a sprayed jet of water at prescribed conditions.

Load Carrying Capacity
Test conducted for evaluation of the capacity of a grease to withstand heavy loads and shock loadings. A Four Ball EP as per ASTM D 2596 and Timken Retention as per US Steel Test Method [9] have been selected for this purpose.

Mechanical Stability
Shear stability is determined by ASTM D 1831 under determined temperatures and water contents.

Wear and Friction Characteristics per SRV Machine
The SRV test consists of a test chamber where 2 test specimens are pressed on each other, as described in reference [1]. The top specimen, which can be a ball, pin, ring, rod or a disk, is oscillated on the bottom specimen (disk) at preprogrammed settings of frequency, stroke, load and temperature. Friction force is automatically calculated as a function of load, and recorded throughout the test. The scar area on the ball and/or the scar dimensions on the disk determine the wear.

Biodegradability
The method OECD 301F (Manometric Respiratory Test) is used to evaluate the biodegradability of the product. The method involves the preparation of a known volume of inoculated mineral medium, containing around 100 mg of sample (at least 50-100 mg ThOD/liter). The system is stirred in a closed flask at a constant temperature (+/-1°C or closer) for up to 28 days. The consumption of oxygen is determined either by measuring the quantity of oxygen (produced electrolitically) required to maintain constant the volume of gas in the respiratory flask, or from the change in volume or pressure (or a combination of both) in the apparatus. Evolved carbon dioxide is absorbed in a solution of KOH or another suitable absorbent. The amount of oxygen taken up by the microbial population during the biodegradation of the product (corrected for uptake by blank inoculum, run in parallel) is expressed as a percentage of ThOD, or less satisfactory, COD.

Laboratory Test Results
The test results obtained on the biodegradable open gear lubricant (BOGL) vs. those obtained on the mining industry standard lubricant (MISL), a petroleum based product, are presented in Table 1.

Table 1: Laboratory Test Results

Characteristic	Test Method	BOGL	MISL
Unworked Penetration / Worked Penetration (UWP/WP)	ASTM D217	379/380	355/372
Visual	- -	Smooth and free of agglomerates	Smooth and free of agglomerates
Film Adhesion	- -	Tacky and adhesive	Tacky and adhesive
Pumpability, Psi @ +30°F Psi @ +20°F	Lincoln Ventmeter	 150 400	 600 1100
Thermal Retention cm @ 100°F cm @ 150°F	- -	 0 0.5	 0 0.5
Reversibility, Points Change, UWP/WP High Temperature (75°C) Low Temperature (0°C) UV (38-42°C)	 - -	 +3/-2 +2/+4 +2/0	 ND ND ND
Dust Resistance, Dust/Grease Weight Ratio (max)	- -	2/1	2/1
Water Sprayoff, % loss	ASTM D4049	2.2	29.1
Four Ball EP, Kg pass	ASTM D2596	800	620
Roll Stability 2 hrs @ 25°C 2 hrs @ 25°C, 10%/w. water 2 hrs @ 45°C, 10%/w. water	ASTM D1831	 +7 -5 -10	 +26 +34 +34
SRV/Steel ball on steel disk(*) COF minimum COF maximum COF @ 1 hr Ball scar diameter, mm Scar depth, µm Scar area, µm^2 Applied Pressure, Psi (calculated after 1 hr run)	 ASTM D5707	 0.10 0.120 0.104 0.94 6.9 - 127,000	 0.11 0.160 0.114 1.35 16.2 - 62,000
SRV/Steel ball on bronze disk(**) COF minimum COF maximum COF @ 1 hr Ball scar diameter, mm Scar depth, µm Scar area, µm^2 Applied Pressure, Psi (calculated after 1 hr run)	 ASTM D5707	 0.07 0.123 0.073 1.05 13.0 - 8500	 0.105 0.130 0.105 1.15 20.0 - 7100
SRV/Steel ring on bronze disk(***) COF minimum COF maximum COF @ 1 hr Applied Pressure, Psi (calculated after 1 hr run)	 ASTM D5707	 0.033 0.134 0.035 1690	 0.053 0.250 0.100(****) 1690
Rust Preventive Characteristics	ASTM D665	Pass	Pass
Biodegradability, %	OECD 301F	62-75	5-8

(*) 600 N, 2.00 mm, 70°C, 50 Hz, 1 hr
(**) 50 N, 1.0 mm, 80°C, 50 Hz, 1 hr
(***) 1000 N, 1200µm, 80°C, 40 Hz, 1 hr
(****) At the failure that occurred after 59 minutes run.

Based on the above results, one can say that BOGL, in comparison to a petroleum based lubricant regarded as the mining industry standard lubricant (MISL), displays equivalent, if not better, physical and performance characteristics. These conclusions are valid for the extreme pressure and anti-wear properties, mechanical stability, water resistance, corrosion inhibition, reversibility, thermal retention and pumpability.

Preparation For Field Testing

The end user, in coordination with the OEM, has requested that BOGL has to pass 2 prerequisite sets of testing; (1) in-house SRV for results confirmation and (2) a compatibility test between BOGL and MISL.

End-user SRV results

Results obtained by the end user are regrouped in Table 2. In this table are presented also the results obtained by the supplier on both BOGL and MISL for comparison purposes.

Table 2: SRV Test Data

Characteristic	BOGL/End user(*)	BOGL/Supplier	MISL/Supplier
SRV/Steel ball on steel disk(*)			
COF minimum	0.075/0.074	0.10	0.11
COF maximum	0.095/0.095	0.120	0.160
COF @ 1 hr	0.075/0.075	0.104	0.114
Ball scar diameter, mm	-	0.94	1.35
Scar depth, µm	4.5/4.3	6.9	16.2
Scar area, μm^2	1900/1950	-	-
Applied Pressure, Psi (calculated after 1 hr run)	-	127,000	62,000
SRV/Steel ball on bronze disk(**)			
COF minimum	0.050/0.050	0.07	0.105
COF maximum	0.065/0.085	0.123	0.130
COF @ 1 hr	0.060/0.065	0.073	0.105
Ball scar diameter, mm	-	1.05	1.15
Scar depth, µm	13.6/13.2	13.0	20.0
Scar area, μm^2	5150/4750	-	-
Applied Pressure, Psi (calculated after 1 hr run)	-	8500	7100
SRV/Steel ring on bronze disk(***)			
COF minimum	0.150	0.033	0.053
COF maximum	0.350	0.134	0.250
COF @ 1 hr	Failure @ 33mn	0.035	0.100(****)
Applied Pressure, Psi (calculated after 1 hr run)	-	1690	1690

(*) Test duplicated

Compatibility Test

Roll Stability Test under prescribed conditions has been used for compatibility test. Results indicated that BOGL in presence of MISL had a tendency to heavy up at a given proportion. An additive, which has been identified in MISL, had the ability to react with the vegetable oil from the BOGL forming a rubber-like product. A secondary standard mining lubricant (MI2SL), with a different additive package, showed excellent compatibility with both BOGL and MISL. These results suggested that the changeover from MISL, currently used in the machine, to the new BOGL, should be implemented through a transition product such as MI2SL. The procedure requires us to have an analytical tool allowing us to determine the content of MISL, M2ISL and BOGL at any time and any point of application where the changeover process was occurring. Each grease contains one specific element, which is not present in the other 2 greases. Simple elemental analysis could provide precise information on the proportion of each grease in the mixture.

Field Testing

Machine trialled: BE 1370 W Dragline
Components trialled: Drag gearings, Center Pintle, Slew rack, Rollers/Rails and RHS Propel Shafts/bushings
Product used prior to the trial: MISL (in use for more than 25 years)
Product used as a transition lube: MI2SL (in use for more than 10 years in equivalent applications)
Product trialled: BOGL
Performance indicators: Visual inspection, sound level, temperatures, and lubricant sample analysis.
General procedure: consists of isolating lubrication systems, purging lines and injectors, loading MI2SL over MISL, dispense product, inspect product appearance in application, sample, check for the proportion MI2SL/MISL.
Repeat the above operations using BOGL to purge the MI2SL once the MI2SL/MISL ratio is close to 90/10. Continue feeding BOGL to the application, sample and check for the MI2SL/MISL/BOGL proportion. Field testing may be started once this ratio is close to 0/0/100.

Drag Gears

Temperatures: Figure 1 shows variation of temperatures registered during the field-testing in function of the length of the lubricating cycle for the drag gear as well as for the rear and front drag pinions. Ambient temperature is also reported.
Sound: Figure 2 shows the level of sound measured in Decibels at the front and rear drags.

Centre Pintle

Temperatures: Figure 3 shows variation of temperatures in function of time and lubrication cycle on the 4 sides of the centre pintle: front, rear, right and left sides.

Propel Bush and Gear

Temperatures: Figure 4, 5 and 6 shows the variation of temperatures in function of the walked steps for the outboard shaft, the main cam shaft bush outer and the main cam shaft gear.

Temperature profiles:
Although the ambient temperature was relatively high during the test of the BOGL, the temperatures registered on the drag gearing pinions and gear have been lower than the temperatures registered in the same positions when the drag gearing was run on MISL. The centre pintle, under the same cycle time, ran slightly cooler with BOGL than with MISL. This trend has been experienced also with the main cam shaft gear, but not likely with the propel bush and the main cam shaft bush, where the situation has been reversed.

Sound level profile:
This was measured only at the drag gearing. No noticeable difference has been observed between BOGL and MISL.

Lubricant sample analysis:
Samples have been supplied on a regular basis in order to monitor the change-over process. Figure 7 shows how the replacement of the MISL by the BOGL took place through the transition product (MI2SL). It took approximately 4 days before getting BOGL at 98% in a spray injector. Longer periods of time were experienced with different lubrication points.

Visual Inspection:
This extract from the final field-testing report [10] summarizes the results of inspection in the following:
At 6 minute purge cycles, the BOGL film was washing off. As cycles were gradually extended, film was being worked and gave good adherence. Film of BOGL is very black-tenacious. Film of BOGL drag gearing is darker than MISL on hoist gearing, appearance excellent. At 30minute cycles for drag gearing, the coverage is still very good and you can still leave finger lines on the load face after 24 hours at 30 minutes cycle. If the adhesion of the lube to the drag gear is anything to go by, I don t think we will have any problems once a film of BOGL has been established. Coverage is very good. Pitch line has plated out nicely. BOGL is still working its way up the non-load side of the drag gear. New BOGL is showing at top flange, centre pintle bushing and temperatures are good .
Later towards the end of the report, we can read: The trial, although clearly in early days, is going very well. MISL, the acknowledged industry standard and our benchmark reference for BOGL, shows early evidence of being outperformed by BOGL .

Conclusions

The lab tests along with the field test results demonstrate that an open gear compound, suitable for an application where superior load carrying capacity, wear protection and water resistance were as important as its biodegradability. This prototype turned out to be the product that met all the challenged requirements: high performance, biodegradation and reasonable cost.

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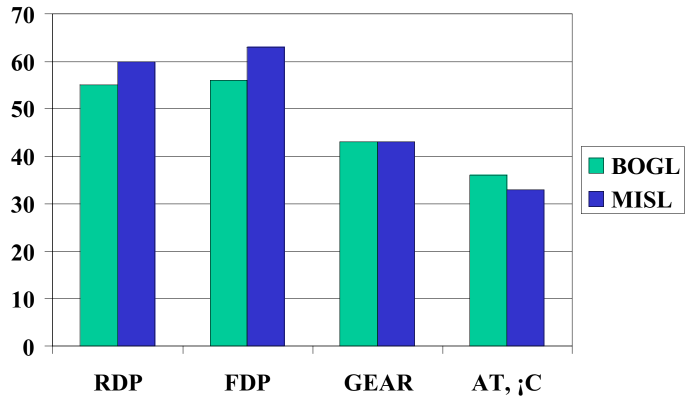
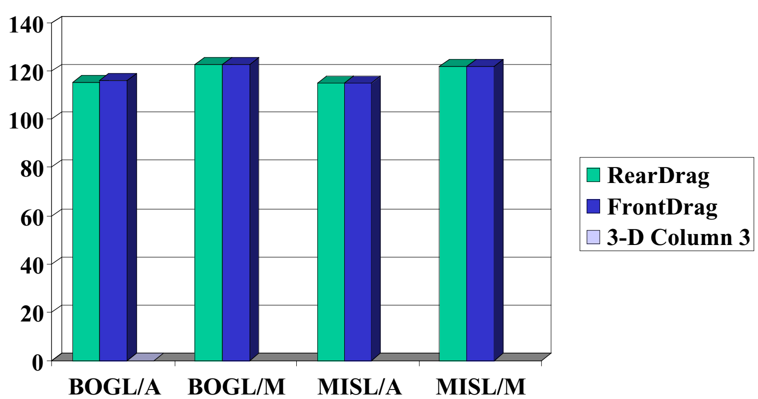
FIGURE 1: DRAG GEARING TEMPERATURE



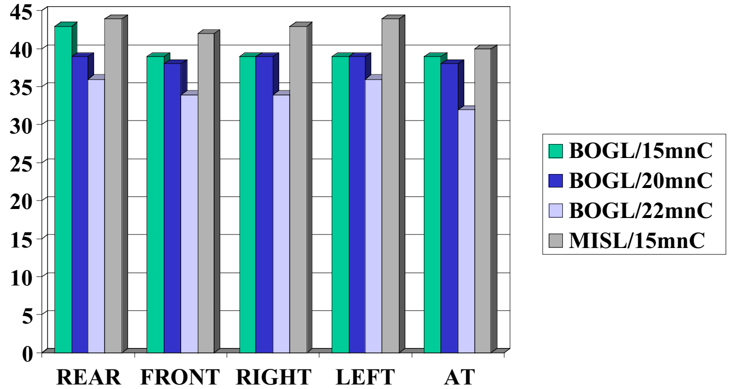
RDP: Rear drag, pinion, FDP: Front drag pinion, AT: Ambient temperature.
BOGL: Biodegradable open gear lubricant, MISL: Mining Industry Standard Lubricant,

FIGURE 2: DRAG GEARING SOUND LEVEL, DECIBELS



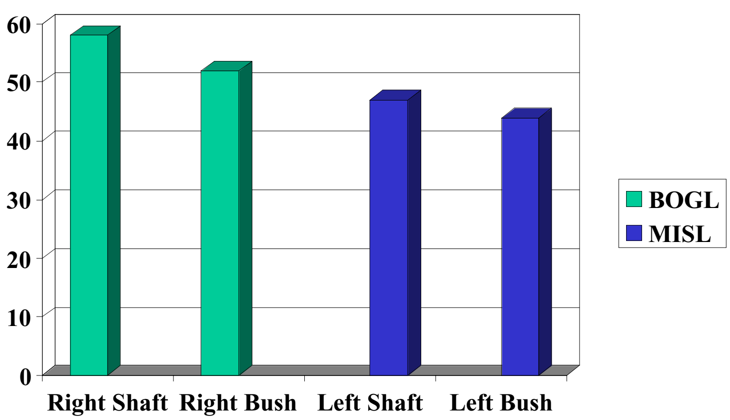
BOGL: Biodegradable open gear lubricant, MISL: Mining Industry Standard Lubricant, M: Max, A: Average

FIGURE 3: CENTRE PINTLE TEMPERATURE



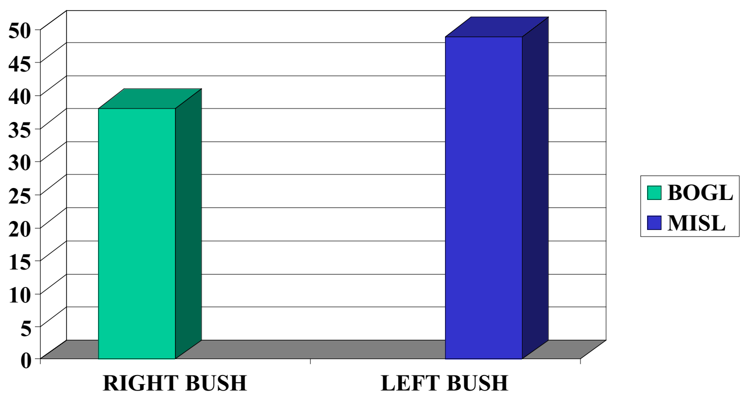
BOGL: Biodegradable open gear lubricant, MISL: Mining Industry Standard Lubricant, AT: Ambient Temperature
15mnC: 15 minutes cycle

FIGURE 4: PROPEL BUSH TEMPERATURE



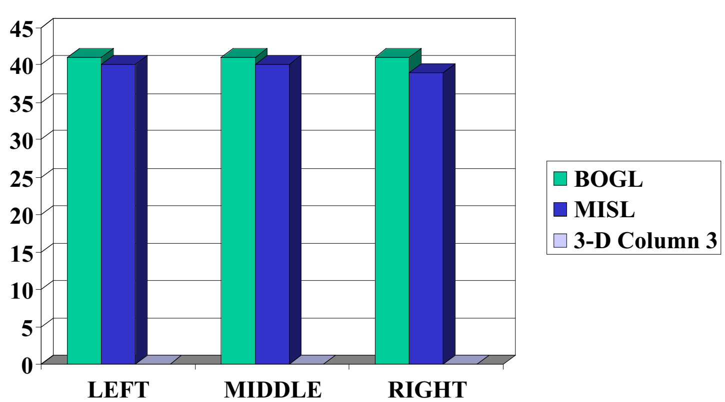
BOGL: Biodegradable open gear lubricant, MISL: Mining Industry Standard Lubricant

FIGURE 5: MAIN CAM SHAFT BUSH TEMPERATURE



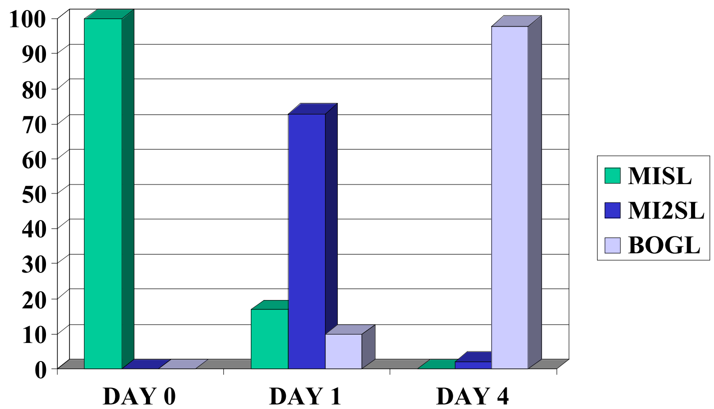
BOGL: Biodegradable open gear lubricant, MISL: Mining Industry Standard Lubricant

FIGURE 6: MAIN CAM SHIFT GEAR TEMPERATURE



BOGL: Biodegradable open gear lubricant, MISL: Mining Industry Standard Lubricant

FIGURE 7: GREASE CHANGEOVER
Front Spray Injector



BOGL: Biodegradable open gear lubricant, MISL: Mining Industry Standard Lubricant, M2ISL: Mining industry secondary standard lubricant