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Alkylated naphthalenes

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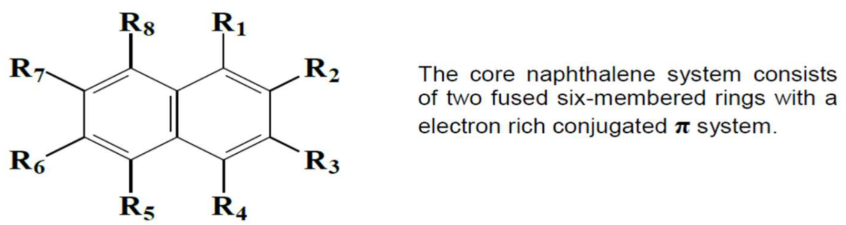
ABSTRACT
Greases are used in numerous applications requiring a broad range of operating temperatures and special requirements, and the base oil used can impart improved characteristics to the grease. Alkylated naphthalenes are a unique class of synthetic fluids with outstanding thermo-oxidative and hydrolytic stability, low volatility, and good solubility characteristics. The flexibility of this technology to achieve a balance of physical and chemical properties will be discussed. Physical property and performance test data will be presented for both liquid lubricants and greases with alkylated naphthalenes as the sole base fluid and as a modifier for other primary base fluids. Grease work has focused on the advantages of using alkylated naphthalenes to reduce the amount of thickener, improve grease clarity and smoothness, and impart significant resistance to oxidation.

INTRODUCTION
Alkylated naphthalenes are high performance synthetic fluids that were first developed during WWII but were never commercialized. In the last 20 years, with advanced processing technology and raw material availability, alkylated naphthalenes have emerged as cost-competitive, high-performance basestocks. These unique synthetic fluids were first used in engine oils and more recently in all types of industrial lubricants and greases. They are primarily used as base oil modifiers with other synthetic base oils or Group II and III mineral oils. They are used to enhance the thermal and oxidative stability and/or additive performance to extend the lifetime of high performance lubricants.

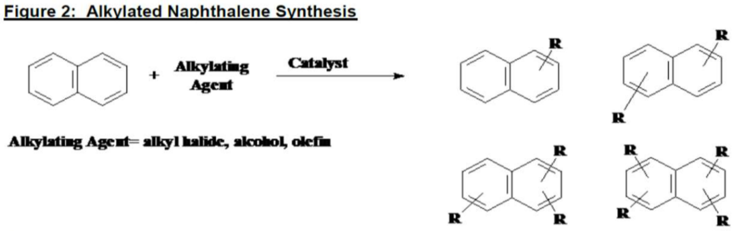
Figure 1: Alkylated Naphthalene Structure



R_1 to R_8 are independently a linear or branched alkyl group or hydrogen

The basic structure of an alkylated naphthalene is shown in **Figure 1**, where the core consists of two fused six-membered ngs with the alkyl groups attached. It is because of the ability of this electron-rich conjugated naphthalene ring to absorb energy, resonate, and disperse energy, much like antioxidants do, that alkylated naphthalenes inherently have excellent thermo-oxidative stability.

Figure 2: Alkylated Naphthalene Synthesis



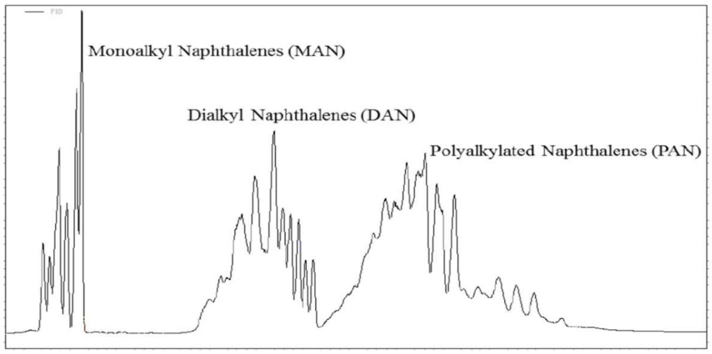
Physical properties depend on:
- Number of *carbons* in the alkyl group (Controlled by raw material selection)
- Degree of branching of the alkyl group (Controlled by raw material selection)
- *Number* of alkyl groups on the naphthalene ring (Controlled by chemical processing)

To make alkylated naphthalenes, naphthalene is reacted with an alkylating agent (alcohols, alkyl halides, or olefins) in the presence of an acid catalyst and this produces a mixture of alkylated naphthalenes having different numbers of alkyl groups on the naphthalene ring. The reaction is shown in F**igure 2**.

The physical properties of alkylated naphthalenes depend on:

- The number of carbons in the alkyl group, which is controlled by raw material selection.
- The degree of branching of the alkyl group, which is controlled by raw material selection.
- The number of alkyl groups on the naphthalene ring, which is controlled by chemical processing.

Figure 3: Gas Chromatography of an Alkylated Naphthalene Mixture Showing the Distribution



GC separates compounds by boiling point.

Figure 3 shows by gas chromatograph the distribution of an alkylated naphthalene mixture showing MAN (mono alkylated naphthalene), DAN (di alkylated naphthalene), and PAN (poly alkylated naphthalene) with three or more alkyl groups on the naphthalene ring (1).

Table 1: Physical Properties of Alkylated Naphthalenes

Linear and branched alkyl groups are of the same carbon number.

Designation	Alkyl Group Structure	Number Alkyl Groups
MLAN	Linear	1
MBAN	Branched	1
PLAN	Linear	2-4
PBAN	Branched	2-4

	MLAN	MBAN	PLAN	PBAN
Kinematic Viscosity @ 40 C (cSt)	**18.2**	**24.2**	**110.5**	**1050**
Kinematic Viscosity @ 100 C (cSt)	**3.4**	**3.5**	**12.8**	**23**
Viscosity Index	**20**	**-**	**110**	**-**
Pour Point (°C)	**-54**	**-36**	**-30**	**3**
Aniline Point (°C)	**1.8**	**-9.2**	**94**	**42**
Flash Point (°C)	**>200**	**>200**	**274**	**214**

Table 1 describes the physical properties of alkylated naphthalenes made with linear and branched alkyl groups of the same carbon number (2). MLAN is a mono linear alkylated naphthalene, so it has one linear alkyl group on the naphthalene ring. MBAN is a mono branched alkylated naphthalene, so it has one branched alkyl group on the naphthalene ring. PLAN is a poly linear alkylated naphthalene, so it consists of two or more linear alkyl groups on the naphthalene ring, and PBAN is a poly branched alkylated naphthalene, so it consists of two or more branched alkyl groups on the naphthalene ring. From the table, one can see that:

- Viscosity increases with increasing number of alkyl groups and with chain branching. So the mono linear alkylated naphthalene has the lowest viscosity.
- Viscosity index (VI) increases with the number of alkyl groups, and linear alkyl groups have better viscosity index because it is easier for them to coil up at low temperatures and expand at high temperatures compared to the branched alkyl chains. Branched alkyl groups are more rigid especially at lower temperatures and this destroys the viscosity index.
- Pour point increases with increasing number of alkyl groups and branching. Mono linear alkylated naphthalenes have the best (lowest) pour points.
- Aniline point, which is a measure of the polarity of a substance and its ability to solubilize polar material, increases with increasing number of alkyl groups but decreases with branching. The lower the number the better the

ability to solubilize polar material.
- Flash points are good for all.

Table 2: API Base Oil Categories

Base Stock Group	Sulfur, wt. %		Saturates, wt. %	Viscosity Index
Group I	> 0.03	and/or	< 90	80 - 119
Group II	≤ 0.03	and	≥ 90	80 - 119
Group III	≤ 0.03	and	≥ 90	≥ 120
Group IV	All Poly-Alpha-Olefins (PAO)			
Group V	All Base Stocks Not Included in Groups I – IV			

Group I: Solvent refined paraffinic base stocks
Group II: Mildly hydrotreated paraffinic base stocks
Group III: Severely hydrotreated paraffinic base stocks
Group V: Esters, glycols, silicones, alkylated aromatics, phosphate esters

In the American Petroleum Institute (API) categories for base oils, as shown in **Table 2**, alkylated naphthalenes are part of the Group V category. Group I, II, and III are paraffinic oils refined from petroleum crude oil with increasing severity of refinement. Group IV base oils are poly-alpha-olefins (PAO). Group V is the catch-all for base oils not included in the other categories.

Figure 4: Generalized Structures of Alkylated Naphthalenes vs. Other Synthetics

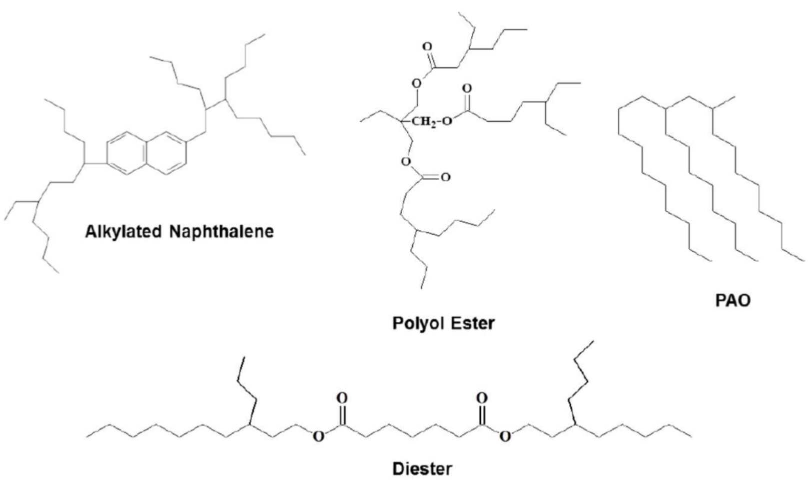


Figure 4 shows the structure of an alkylated naphthalene compared to other synthetic lubricants, including a PAO, a polyol ester, and a diester.

Compared to mineral oils, PAOs, esters, and polyalkylene glycols (PAG), alkylated naphthalenes have several performance advantages, as shown in **Table 3**.They provide superior thermo-oxidative stability because of the electron-rich naphthalene ring and its ability to resonate and disperse energy.

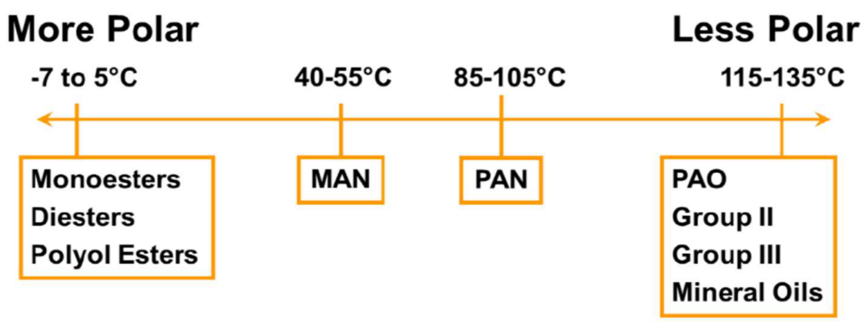
Alkylated naphthalenes have inherent hydrolytic stability because they do not contain any functional groups that can hydrolyze. They have good seal swelling properties - better than Group II and III mineral oils and PAOs. They have better additive solubility than Group II and III mineral oils and PAOs, and this is again because of the aromatic ring of the alkylated naphthalene. They also have good low pour points and greater film thickness and film strength, which can reduce friction.

Table 3: Comparison of Some Lubricant Base Fluids

	Mineral Oils (Group II & III)	PAO (Group IV)	Esters	PAGs	*Alkylated Naphthalenes*
Thermo-Ox Stability	Good	Good	Fair to Exc.	Good	*Excellent*
Thermal Stability	Excellent	Excellent	Excellent	Excellent	*Excellent*
Hydrolytic Stability	Excellent	Excellent	Poor to Good	Excellent	*Excellent*
Seal Swell	Poor	Poor	Excellent	Good	*Good*
Viscosity Index	Good	Excellent	Excellent	Excellent	*Good*
Additive Solubility	Fair to Poor	Poor	Excellent	Good	*Good to Exc.*
Pour Point	Good	Excellent	Excellent	Excellent	*Good*
Film Thickness	Fair	Good	Good	Good	*Excellent*

As previously mentioned, another property used to characterize oils is aniline point. This is an indirect measure of the polarity of a substance and its ability to solubilize polar materials. A low aniline point is indicative of a fluid with high polarity and good solubilizing characteristics. As shown in **Figure 5**, the aniline point of alkylated naphthalenes is between esters, which have high polarity, and mineral oils and PAOs, which are non-polar.

Figure 5: Aniline Point



Alkylated naphthalenes can aid in solubilizing additives in non-polar base stocks.

So alkylated naphthalenes can be used to help solubilize additives in non-polar base stocks, and, like esters, are often added to PAOs. However, alkylated naphthalenes do not incorporate hydrolytic instability or compete with additives for the surface as esters can. The mono alkylated naphthalenes are more polar than the poly alkylated naphthalenes.

In today's marketplace, alkylated naphthalenes are available with a diverse ISO viscosity range from 22-193 cSt at 40°C, as shown in **Table 4**. In general, as the viscosity increases:

- Viscosity index increases
- Aniline point increases, which means the solubility decreases
- Volatility decreases significantly
- Pour point increases
- Flash point increases
- Oxidative stability remains excellent
- Thermal stability remains excellent

Several alkylated naphthalenes are also approved by the U.S. FDA for use as H1 "Lubricants with Incidental Food Contact" per 21 CFR 178.3570, where they can be used up to 100% if needed to achieve the desired technical effect. Some are NSF listed as HX-1 additives.

The primary areas of application for alkylated naphthalenes include:

- Automotive and Stationary Engine Oils
- Automotive and Industrial Gear Oils
- High Temperature Chain Lubricants
- Paper Machine Oils
- Hydraulic Oils
- Circulating Oils / Turbine Oils / R&O Oils
- Screw Compressor Oils
- Heat Transfer Oils
- Automotive and Industrial Greases

Table 4: Alkylated Naphthalene Properties

PROPERTY	AN-7A	AN-8	AN-9	AN-15	AN-19	AN-23
Viscosity @ 40°C	21.8 cSt	36 cSt	39 cSt	114 cSt	177 cSt	193 cSt
Viscosity @ 100°C	3.8 cSt	5.6 cSt	5.7 cSt	13.5 cSt	18.7 cSt	19.8 cSt
Viscosity Index	22	90	80	110	118	118
Aniline Point	40°C	42°C	pending	94°C	103°C	NA
Noack Volatility, by wt	39%	12%	6.4%	2.2%	1.4%	<1.0%
Evaporation Loss, 6.5 hrs. @ 205°C	55.20	10.98	pending	3.82	1.36	0.42
Pour Point	< -48°C	-33°C	pending	-39°C	-26°C	-21°C
Flash Point	206°C	236°C	>250°C	260°C	285°C	310°C

EXPERIMENTAL

In this paper, alkylated naphthalenes are evaluated both as neat fluids and as base oil modifiers using the following tests (3).

- Thermal Stability
  - Federal Test Method 3411
  - Cincinnati Milacron - ASTM D 2070
- Thermo-oxidative Stability
  - Panel Coker - Federal Test Method 791-3462
  - Rotating Pressure Vessel Oxidation Test (RPVOT) - ASTM D 2272
  - Pressure Differential Scanning Calorimetry (PDSC) - ASTM D 6186
- Hydrolytic Stability
  - Beverage Bottle Test - ASTM D 2619
- Volatility
- Low Temperature Performance
  - Viscosity vs. Temperature with VI and PPD
- Friction
  - FZG - ASTM D 5182
- EHD (Elastohydrodynamic) Film Thickness and Pressure-Viscosity Coefficient
- Seal Swell
  - Volume Change and Hardness Change - ASTM D 4289 and ASTM D 471
- Grease
  - Pressure Differential Scanning Calorimetry (PDSC) - ASTM D 5483

RESULTS AND DISCUSSION

Thermal Stability

Federal Test Method 3411

In Federal Test Method 3411, samples are held at 274□C for 96 hours in the presence of a steel coupon in a sealed glass tube. The test evaluates the change in viscosity, increase in acid number, steel coupon weight loss, steel coupon appearance, and appearance of the oil. **Table 5** shows that neat samples of AN-15, AN- 19, and AN-23 did not undergo any significant decomposition using this test method.

Table 5: Thermal Stability (FTM 3411)

274°C for 96 hours with steel coupon in sealed glass tube

	AN-15	AN-19	AN-23
% Change in Kinematic Viscosity @ 40°C	+0.6%	+0.7%	+0.1%
Initial Acid Number (mg KOH/g)	0	0	0.02
Change in Acid Number	0	0	-0.02
Change in Metal Weight (mg/cm^2)	+0.017	+0.034	+0.033
Appearance of Metal	Dull Brown	Dull Brown	Dull Brown
Sediment	None	None	None
Original Oil Appearance	Light Yellow	Light Yellow	Yellow
Final Oil Appearance	Light Yellow	Light Yellow	Yellow
Test Cell Appearance	Clean	Clean	Clean

A 7 cSt Group III base oil was also evaluated and compared to 20% modifications with AN-15, a trimethylolpropane (TMP) ester, and a diester. **Table 6** shows that the Group III oil modified with the alkylated naphthalene exhibited excellent performance while the oils containing the esters resulted in thick, dark deposits and, in one case, extensive degradation of the metal.

Table 6: Thermal Stability (FTM 3411)

274°C for 96 hours with steel coupon in sealed glass tube

	7 cSt Group III	20% AN-15 80% 7 cSt Group III	20% TMP Ester 80% 7 cSt Group III	20% Diester 80% 7 cSt Group III
% Change in Kinematic Viscosity at 40°C	**-0.86**	***-0.80***	**-10.02**	**-15.78**
Change in Acid Number	**0.03**	***-0.03***	**5.97**	**0.52**
Change in Metal Weight, (mg/cm^2)	**0**	***-0.008***	**-2.97**	**0.05**
Appearance of Metal	**Gold Shiny**	***Shiny***	**Etched**	**Blue-Black Shiny**
Final Oil Appearance	**Clean**	***Light Amber***	**Black**	**Very Dark Amber**
Test Cell Appearance	**Clean**	***Clean***	**Heavy Black Stains**	**Clean**

A 7 cSt Group III base stock has been modified with different Group V base stocks.

Cincinnati Milacron - ASTM D 2070

Cincinnati Milacron testing was also conducted. In this test, 200 ml of the test fluid is held at 135°C for 7 days in the presence of copper and steel rods. Measurements include sludge formation, copper rod rating, steel rod rating, change in viscosity, and change in acid number. Even though the test is normally run at 135°C, testing was conducted at higher temperatures. **Table 7** shows that when tested at 150°C, AN-15, AN-19, and AN-23 all showed good performance with little change.

Table 7: Thermal Stability - Modified Cincinnati Milacron ASTM D 2070

Copper and steel rods in 200 ml test oil (Test run at 150ºC, 7 days)

	AN-15	AN-19	AN-23
% Viscosity Change	**3.8**	**2.1**	**4.0**
Acid Number Change (mg KOH/g)	**0.03**	**0.03**	**0.02**
Total Sludge (mg/100ml)	**0.55**	**0.65**	**0.50**
CM Color Class - Copper	**2**	**3**	**2.5**
CM Color Class - Steel	**1.5**	**1**	**1**

Original test procedure is run at 135ºC, 7 days.

Table 8 shows the test results at 200 °C comparing AN-15 to a PAO blended to the same viscosity. Even though the sludge was equivalent, the PAO experienced a very high viscosity increase.

Table 8: Thermal Stability - Modified Cincinnati Milacron ASTM D 2070

Copper and steel rods in 200 ml test oil (Test run at 150ºC, 7 days)

	Neat Fluid	
	Total Sludge (mg/100ml)	% Viscosity Increase
AN-15	**2.8**	**8**
PAO*	**2.1**	**100**

Original test procedure is run at 135ºC, 7 days.
* PAO is 114 cSt @ 40°C - Blend adjusted to equal viscosity of AN-15.

At 225°C, **Table 9** shows that both these fluids resulted in equivalent sludge, but again the PAO experienced a very high viscosity increase, even with the addition of 1.5% of a package containing antioxidants, a yellow metal deactivator, and a rust inhibitor.

Table 9: Thermal Stability - Modified Cincinnati Milacron ASTM D 2070

Copper and steel rods in 200 ml test oil (Test run at 150°C, 7 days)

	Neat Fluid		Base Fluid with 1.5% AOP*** @ 225°C	
	Total Sludge (mg/100ml)	% Viscosity Increase	Total Sludge (mg/100ml)	% Viscosity Increase
AN-15	**19.9**	**20**	**8.1**	**20**
PAO**	**13.6**	**332**	**8.1**	**164**

Original test procedure is run at 135ºC, 7 days
** PAO - 114 cSt @ 40°C - Blend adjusted to equal viscosity of AN-15.
*** Additive Package containing antioxidants, yellow metal deactivator, and rust inhibitor.

Thermo-oxidative Stability

Panel Coker - FTM 791-3462

In Panel Coker testing, oil is splashed against a test panel at elevated temperatures and the amount of coke deposited on the panel is determined by weight. As shown in **Table 10**, modifying a PAO with 10% of AN-8, AN-15, and AN-19 significantly reduced the amount of coke formed. The neat PAO resulted in 9 mg of coke, while the PAO modified with alkylated naphthalene resulted in much less. This is also evident by the pictures showing the 100% PAO result on the left and the PAO modified with 10% AN-15 on the right.

Table 10: Thermal Stability - Panel Coker FTM 791-3462

	100% PAO (ISO VG 220)	10% AN-8 90% PAO	10% AN-15 90% PAO	10% AN19 90% PAO
Coking Value (mg)	**9.0**	**1.0**	**3.0**	**2.0**


Temperature Conditions: Test Panel: 200°C Oil Sample: 140°C

Rotating Pressure Vessel Oxidation Test (RPVOT) - ASTM D 2272

RPVOT testing was conducted where 50 g of test fluid and 5 ml of water with a copper coil catalyst are pressurize to 90 psi with oxygen and then held at 150 °C. The time required for the pressure to drop to 25 psi is defined as the lifetime of the sample.

Table 11 shows that neat fluids of AN-15, AN-19, and AN-23 showed superior thermo-oxidative stability compared to a PAO of equal viscosity to the AN-15. The alkylated naphthalenes also showed very good additive response, resulting in very high RPVOT lifetimes compared to the PAO when additized with 0.2% of di-tertiary butyl phenol (DTBP) and alkylated di-phenyl amine (ADPA) antioxidants versus the PAO. This was especially noted with the ADPA. The excellent thermo-oxidative stability of alkylated naphthalene is the result of the electron-rich naphthalene ring, which can scavenge radicals, resonate, and disperse the energy.

Table 11: Thermo-oxidative Stability - RPVOT ASTM D 2272

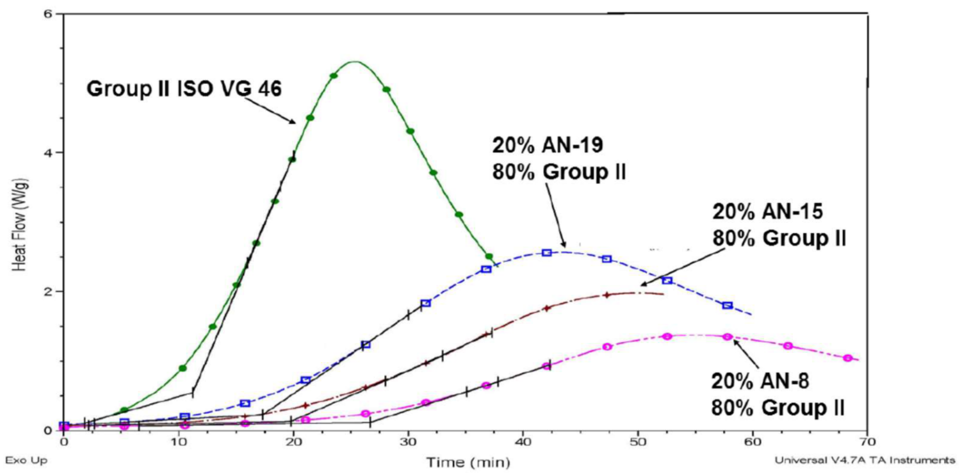
	PAO*	AN-15	AN-19	AN-23
Lifetime (minutes) neat fluid	19	87	89	101
Lifetime (minutes) with 0.2% Phenolic AO - DTBP	44	179	204	241
Lifetime (minutes) with 0.2% Aminic AO - ADPA	34	409	532	521

* **PAO is 114 cSt @ 40°C - Blend adjusted to equal viscosity of AN-15.**

Table 12 shows the AN-8 being used to boost the RPVOT performance of a Group III oil containing 0.7% of an R&O package. Replacing 15% of the Group III oil with alkylated naphthalene increases the oxidation lifetime from 1339 to 1926 minutes but also significantly reduces the sludge in the Cincinnati Milacron test.

Figure 6: Thermo-oxidative Stability - PDSC ASTM D 6186

Isothermal @ 160°C, 500 psi Oxygen
Group II vs. 20% Alkylated Naphthalene in Group II

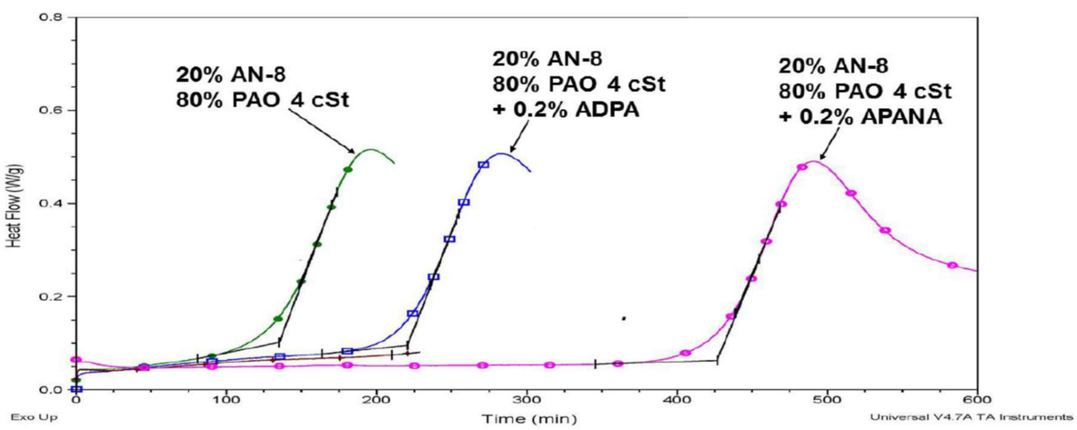


Pressurized Differential Scanning Calorimetry (PDSC) - ASTM D 6186

PDSC measures the oxidation induction time to an onset of an exotherm under specific conditions. Testing was conducted using 2 mg samples at 500 psi and 160°C. An ISO VG 46 Group II oil was compared to the Group II oil modified with 20% of AN-8, AN-15, and AN-19, as shown in **Figure 6**. The addition of the alkylated naphthalene increased the oxidation induction time and reduced the rate of oxidation. The degree of improvement depended upon which alkylated naphthalene was used.

Figure 7: Thermo-oxidative Stability – PDSC ASTM D 6186

Isothermal @ 160°C, 500 psi Oxygen
20% AN-8 in PAO 4 cSt with 0.2% Antioxidant



Also tested was a PAO modified with 20% AN-8 with and without antioxidant. **Figure 7** shows that the oil combination exhibited good additive response, increasing the oxidation induction time with 0.2% alkylated di- phenyl amine (ADPA) and alkylated phenyl alpha naphthylamine (APANA).

Hydrolytic Stability

Beverage Bottle Test - ASTM D 2619

In the Hydrolytic Stability Beverage Bottle test, a 75 g sample, 25 g of distilled water, and a copper test strip are sealed in a Coca-Cola bottle. The bottle is rotated for 48 hours in an oven at 93°C. Measurements include total acidity of the water, copper loss, appearance of the copper strip, and the acid number change of the oil.

Two neat alkylated naphthalenes, AN-15 and AN-19, were tested and showed excellent hydrolytic stability, as shown in **Table 13**. As mentioned earlier, alkylated naphthalenes do not contain functional groups that tend to hydrolize.

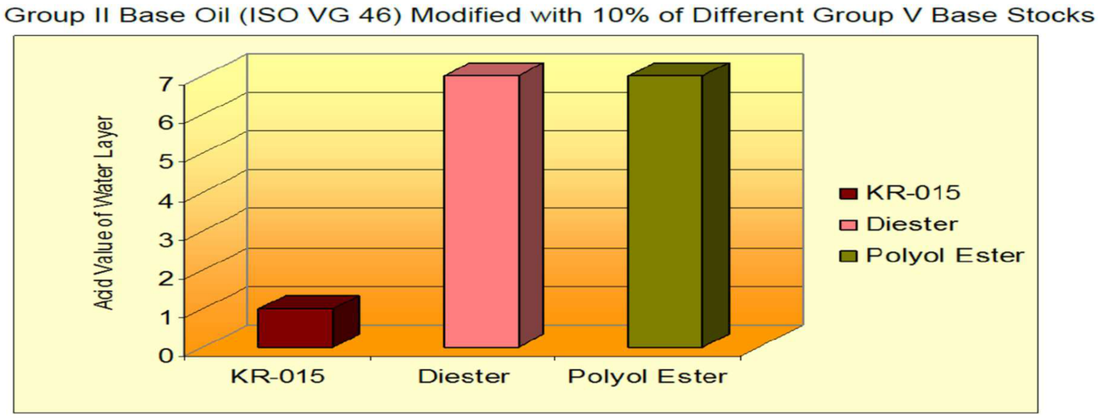
Table 13: Hydrolytic Stability – Beverage Bottle Test ASTM D 2619

Neat Alkylated Naphthalenes

	NA-LUBE AN-15	NA-LUBE AN-19
Hydrolytic Stability (ASTM D 2619) TAN Increase (mg KOH/g)	0.02	0.02

Figure 8 shows the beneficial effect of adding 10% AN-15 to an ISO VG 46 Group II base oil compared to adding a diester and a polyol ester. The esters are hydrolytically unstable and this results in high acid values of the water layer.

Figure 8: Hydrolytic Stability – Beverage Bottle Test ASTM D 2619



Volatility

Thin film testing was conducted using 2 g of fluid in an aluminum pan for 24 hours at temperatures of 200 °C, 225 °C, and 250 °C. As shown in **Table 14**, AN-15 showed less volatility at the lower temperatures than a PAO of equal viscosity. A second alkylated naphthalene, AN-19, also resulted in good volatility. **Table 15** shows that a 40 cSt PAO had higher volatility than the AN-19, and when 20% of the alkylated napthalene was added to the PAO, the volatility was brought down to the level of the alkylated naphthalene alone. For comparison, an ester at 20% in the PAO resulted in significantly higher volatility.

Table 14: Thin Film Volatility

2 grams in aluminum pan for 24 hours

	Neat Fluid - Weight Loss, %		
	200°C	225°C	250°C
AN-15	12.0	26.7	67.4
PAO*	41.1	50.6	65.1

* PAO is 114 cSt @ 40°C - Blend adjusted to equal viscosity of AN-15.

Low Temperature Performance

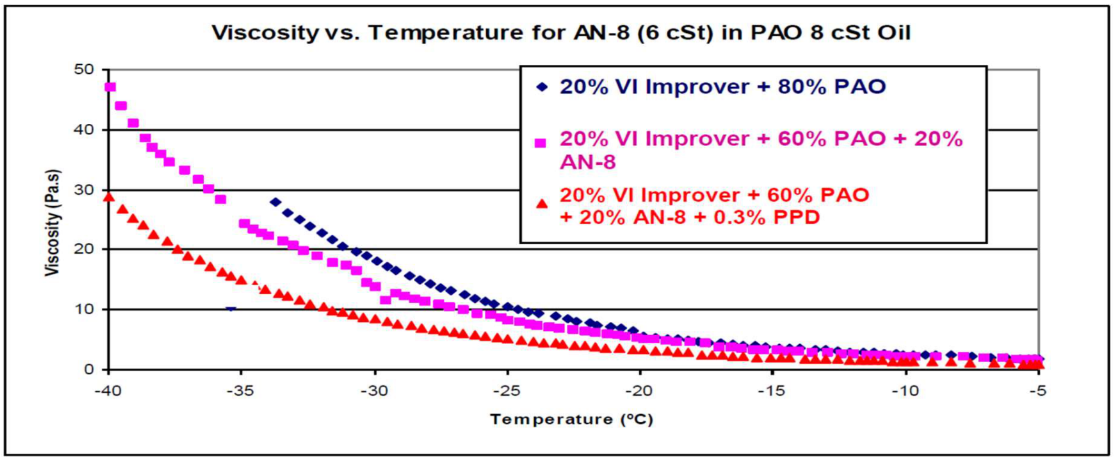
Viscosity versus temperature profiles were run as shown in **Figure 9**. The upper line is for an 8 cSt PAO containing 20% viscosity index (VI) improver. When 20% of the PAO is replaced with AN-8, the viscosity temperature profile is improved, and further improvement is realized with the addition of 0.3% of a pour point depressant (PPD).

Table 15: Thin Film Volatility

2 grams in aluminum pan for 24 hours

	Weight Loss, %		
	200°C	225°C	250°C
AN-19	8.5	19.7	41.6
PAO 40	17.9	29.8	45.4
20% AN-19 / 80% PAO 40	9.4	20.2	39.6
20% Ester / 80% PAO 40	28.5	43.1	56.7

Figure 9: Low Temperature Viscosity Profile

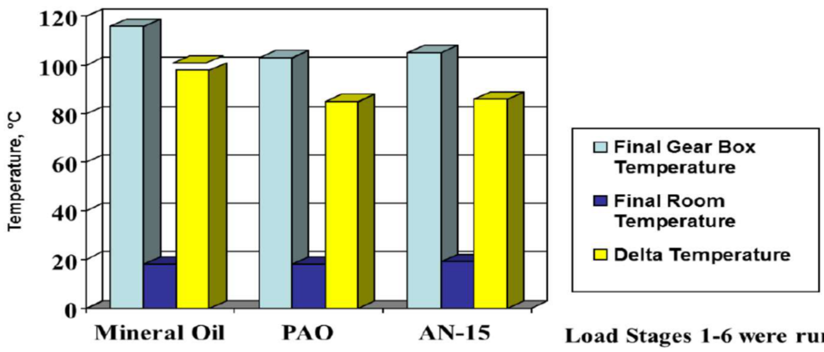


FZG Friction Performance - ASTM D 5182

In the standard FZG test, gears are run at increasing load stages at a constant speed of 1450 rpm for 21,700 revolutions (about 15 minutes) per load stage until scuffing occurs.

Figure 10: Friction Study – FZG Modified ASTM D 5182

Test Oils with 0.3% AW additive



Load Stages 1-6 were run in accordance to ASTM D 5182. Load Stage 7 was applied for an 8-hour duration.

	Mineral Oil	PAO	AN-15
Viscosity @ 40°C (cSt):	117.5	124.1	114.5
Viscosity @ 100°C (cSt):	12.6	16.9	13.5
V.I.:	98	148	110

Figure 10 shows the results of a modified procedure where the first 6 load stages were run in accordance to the ASTM method. Then Load Stage 7 was applied for an 8-hour duration and the temperature difference between the gear box and the room was determined. AN-15 was compared to a mineral oil and PAO of similar viscosity, each containing 0.3% of an AW additive. AN-15 showed less frictional heat than the mineral oil and was equivalent to the PAO.

EHD (Elastohydrodynamic) Film Thickness and Pressure-Viscosity Coefficient

A WAM machine was used where a optical interferometer measures fluid film thickness between a rotating Pyrex disc and a smooth 2 cm freewheeling steel ball. The load applied was 44.4N, and optical measurements to determine film thickness were made at a rolling velocity of 2 m/sec and temperatures of 45 °C and 100 °C. From the film thickness data, pressure-viscosity coefficients were calculated using the Hamrock-Dowson formula for point contacts. Pressure-viscosity coefficients are a good measure of film forming capability to protect the metal surface at different speeds and temperatures in rolling contact zones.

Table 16: EHD Film Thickness and Pressure-Viscosity Coefficient

	4 cSt Polyol Ester	4 cSt AN
	nm	**nm**
EHD Film Thickness at 2 m/sec and 45°C	**170**	**225**
EHD Film Thickness at 2 m/sec and 100°C	**40**	**52**
	GPa	***GPa***
Pressure-Viscosity Coefficient at 2 m/sec and 45°C	**8.5**	**15.6**
Pressure-Viscosity Coefficient at 2 m/sec and 100°C	**3.9**	**7.5**

An alkylated napthalene and a polyolester of the same viscosity were tested, and the film thicknesses and pressure-viscosity coefficients are reported in **Table 16**. The alkylated naphthalene resulted in thicker films and superior (higher) pressure-viscosity coefficients showing better film forming capability.

Seal Swell Performance - ASTM D 4289 and ASTM D 471

Neat AN-19 was tested with three different seal materials using the ASTM D 4298 test. **Table 17** shows that AN-19 imparted seal swell to the different elastomers.

Table 17: Seal Swell - ASTM D 4289 (Neat AN-19)

	Volume Change	Hardness Change (points)
Chloroprene @100°C, 240 hours	11.2%	-5
Fluorocarbon @150°C, 240 hours	0.1%	-2
Nitrile Butadiene @150°C, 240 hours	3.8%	-1

Using a nitrile seal material, a 20% addition of AN-15 to a 7 cSt Group III oil was compared to the Group III alone using ASTM D 471. **Figure 11** shows that the alkyated naphthalene was able to impart seal swell properties to the non-polar Group III base oil.

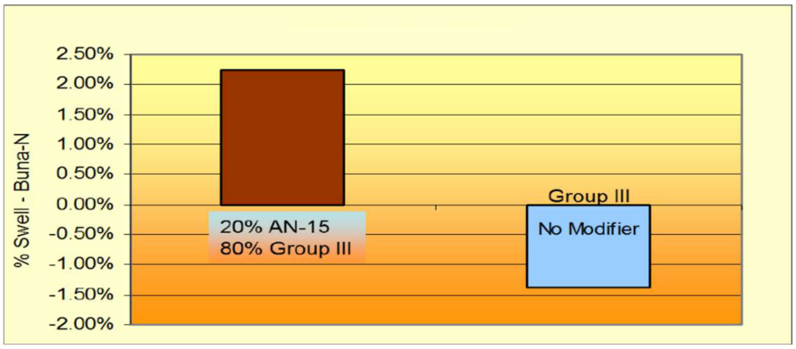
Greases Made with Alkylated Naphthalenes

Lithium 12-hydroxystearate greases made with AN-15 and PAO of a similar viscosity were also evaluated. The grease made with the alkylated naphthalene had several improved properties over the grease made with the PAO, as shown in Table 18. The grease made with AN-15 required less thickener – 7% compared to 12% for the PAO grease.

Less thickener can result in improved low temperature properties. The alkylated naphthalene grease was also more transparent than the PAO grease. This can be seen in **Figure 12** and is probably because the alkylated naphthalene acts as a bridging solvent, reducing the opaqueness of the grease.

The AN-15 grease was also a smoother grease than the PAO grease probably because the alkylated naphthalene acts as a highly effective dispersant. The AN-15 grease also resulted in superior thermal gravimetric analysis and PDSC performance, liberating very small amounts of heat.

Figure 11: Seal Swell - ASTM D 471



Alkylated naphthalene will improve the seal swell properties of non-polar base oils.

Pressurized Differential Scanning Calorimetry (PDSC) - ASTM D 5483

Table 18: AN-15 vs. PAO 10 in Li-12-OH Grease

Lithium 12-Hydroxystearte NLGI #2

	PAO 10 (88%) Li 12-OH Stearate (12%)	AN-15 (93%) Li 12-OH Stearate (7%)
Color / Appearance	Tan / Opaque	Amber / Transparent
P (0) P (60) P (10K) P (100K)	275 273 309 350	285 288 335 366
Oil Separation	4.1%	2.8%
Dropping Point	202°C	200°C
Viscosity @ -40°C	4.0 x 106 mPa.s	6.6 x 106 mPa.s
TGA	233°C	304°C
PDSC (500 psi O_2, 210°C)	400 W/g after 3.7 minutes	5 W/g after 5 minutes

PDSC testing was conducted using greases made with the same lithium 12-hydroxystearate thickener but with blends of different oil ratios of AN-15 and PAO. In this test, 2 mg of grease was place in an aluminum test pan and the temperature was ramped at 100°C/min to the test temperature. Then the sample was allowed to equilibrate at the test temperature for 2 minutes. The oxygen valve was opened, and the system was pressurized to 500 psi within 2 minutes. When equilibrated, the oxygen was adjusted to a flowrate of 100 ml/min. Note that the oxidation induction time is measured from the time when the oxygen valve is opened. **Figure 13** shows the temperature ramp to the test temperature, the 2 minute equilibration, and the opening of the oxygen valve, which always causes a spike.

Figure 12: Grease Color / Appearance

Alkylated Naphthalene

Less thickener = improved low temperature properties

Bridging solvent = reduced opaqueness

Effective dispersant = smooth grease

Figure 14 shows PDSC test results at 180°C. The temperature ramp, the 2 minute equilibration, the oxygen valve opening, and the spike can clearly be seen followed by whatever happens afterwards. The grease made with 100% Group III oil was the least stable and oxidized immediately and quickly. The grease made with 100% PAO was better but also oxidized quickly. Modifying the PAO with 10% AN-15 imparted oxidation resistance to the grease. Modifying the PAO with 50% alkylated naphthalene imparted significant oxidation resistance making the grease completely stable and equivalent to the grease made with 100% alkylated naphthalene.

Figure 13: Thermo-oxidative Stability – PDSC ASTM 5483 Explanation

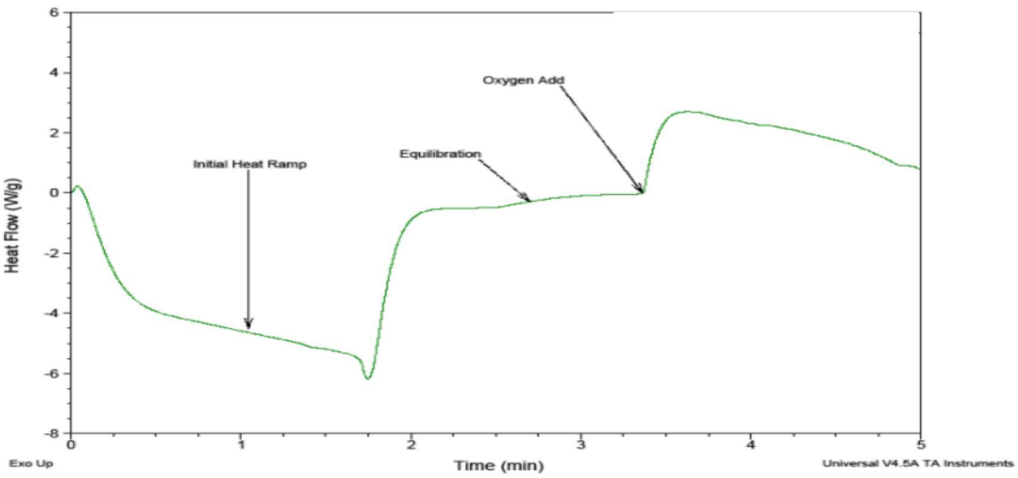
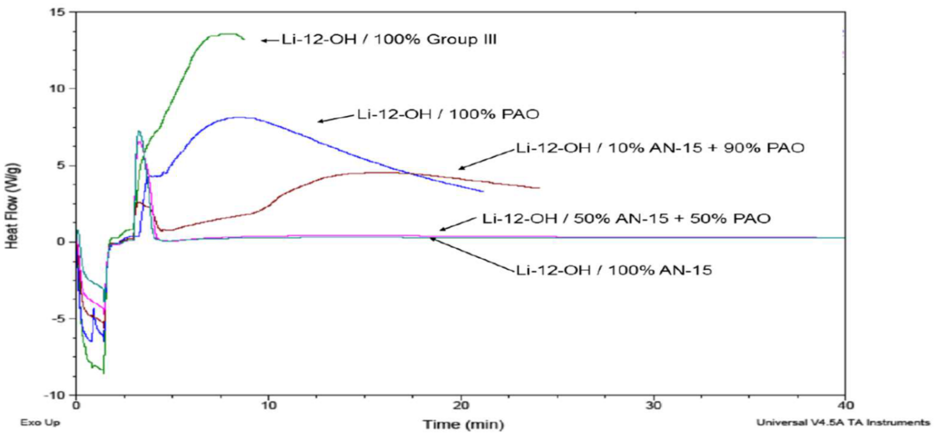


Figure 14: Thermo-oxidative Stability – PDSC ASTM D 5483 at 180ºC



CONCLUSIONS

So why use alkylated naphthalenes? Alkylated naphthalenes are high performance synthetic fluids available in a diverse ISO viscosity range from 22-193 cSt for flexibility in designing lubricants for specific applications.

They have many superior performance properties over other oils and are able to impart these advantages when added to other oils and greases. They provide excellent thermal and thermo-oxidative stability because of the electron-rich naphthalene ring and its ability to resonate and disperse energy. Alkylated naphthalenes have inherent hydrolytic stability because they do not contain functional groups that can hydrolyze. They have good seal swelling properties - better than Group II and III mineral oils and PAOs. They have better additive solubility than Group II and III mineral oils and PAOs and less surface competition than seen with polar esters. Alkylated naphthalenes have good pressure-viscosity coefficients, film thickness, and film strength, which can reduce friction. They also have good low pour points.

Greases made with alkylated naphthalenes also have several advantages over greases made with PAO, including less required thickener, improved transparency, and a smoother texture. Alkylated naphthalenes also have superior thermo-oxidative stability than PAO and are able to impart this stability to PAO greases.

REFERENCES

1. Hourani, M.J., Hessell, E.T., Abramshe, R.A., and Liang, J.G., "Alkylated Naphthalenes as High Performance Synthetic Fluids," Tribology Transactions, 50: 82-87, 2007.
2. Hessell, E.T. and Abramshe, R.A., "Alkylated Naphthalenes as High Performance Synthetic Fluids," Journal of Synthetic Lubrication, 20-2, 2003.
3. ASTM Annual Books of ASTM Standards, Volumes 05.01, 05.02, and 05.03, Petroleum Products, Lubricants and Fossil Fuels, 2013.

Lubrication Management - Key To Maintenance Excellence

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Abstract

All throughout history, many have looked for ways to reduce friction. Certainly, ancient armies used grease as a weapon where by they would ignite the oil and wield it at their foe. Grease and oil was used for medicinal purposes as applied to the body. On a more industrious note, while building the pyramids, ancient Egyptians used crude types of greases to lubricate the axels of pharaoh's chariots.

Time has passed since the introduction of lubrication in industry; the sophistication of machinery has changed as well. The different materials used in combination to increased loads and speeds have forced lubrication manufacturers to meet growing needs. But what has really changed? Lubrication still performs the same function as before: friction reduction, but what is different about the lubricants of today? With all the different lubricants to choose from for each application, a better question might be, "what do I need to know in order to ensure I am getting the most out of the lubrication used in my plant?"

"Billions of dollars are spent world wide each year to repair of damage from mechanical wear in factories caused by surface degradation, including mechanical wear and fatigue." [1].

The purpose of this paper is to provide a balanced start in the investigation into lubrication management for an equipment end-user. It would be impossible to cover everything one needs to know about managing your plant's lubrication issues in one article. Instead, the intention here is to provide an understanding of lubrication management through the use of terms and definitions, current techniques and best practices, and other resources. The article is set-up as follows:

- Lubrication strategy – **Why** Bearing Fail
- Road map for Lubrication Management –**Where**, **How** & **What** to improve
- Lube Management - case study from Hindalco, Belgaum

Note: Written approval is available from Hindalco, Belgaum for external publication of the data related to Lube Management Program.

Introduction:

Lubrication Strategy -Why Bearings Fail

Some still valid statistics regarding the failure of bearings are provided by SKF. Certain industries of course vary from the statistics quoted, but in general the percentages are a sound indicator of the different failure modes. These reasons are:

- 36 % -Lubrication problems
- 14% - Contamination, e.g., dirt, water, particles16% - Poor fitting
- 34% - Fatigue, e.g., overload, temperature too low/high, alignment, mounting

Lubrication and contamination accounts for half of the failures. Lubrication problems include wrong lubricants, insufficient lubrication, too much lubrication, and contaminated lubrication.

Sources listed for contamination problems include contaminated environment, contaminated lubricants, ineffective seals, damaged seals, and wear. Enough reason to have a closer look into the lubrication strategy. Let's consider various components of a lubrication strategy, including possible improvement actions.

Manual and Automatic Lubrication

The manual and automatic lubrication practices can suffer by various reasons. For example, lack of dedicated resources, low competence levels, bad understanding of lubrication effects on reliability, antiquated lubrication systems, inaccessible lubrication points, lack of defined lubrication schedules, and undesired mixing lubricants. In order to improve, lubrication training, modern automatic systems, implementation of a lubrication management program compatible to the relevant computerized maintenance management system (CMMS), and appropriate lubrication coding and identification could be included in the lubrication strategy.

Lubrication Knowledge

Low or lack of knowledge on the effects of contamination on component and asset performance, grease/oil lubricant selection, and use of automated lubrication systems, may be the reason of unnecessary lubrication problems. This could be a reason to educate the in-house resources on contamination effects, lubricant selection, use of lubrication systems, etc., or partnering with competent lubrication services providers. Also crucial is to make management aware of the effects of lubrication on asset performance/availability.

Data Management Processes

The lubrication (data) management processes and databases may suffer due to incomplete content (lubrication types, quantities per point, routing schedule, machine requirements), lack of dedicated resources to manage the data, or lack of interface with work activity systems like CMMS. Possible improvements include completing the information in professional and accessibledatabases per lubrication point, training dedicated resources, implementing an lubrication management systems with status information and connection to CMMS.

Cleanliness Control

Contamination definitely could be a major driver for improvements due to various reasons. Examples include lack of closed lubrication systems, limited structure to eliminate lubricant mixing, poor filtration systems, lack of dedicated flushing of equipment, contamination ingress during sampling, poor follow-up of lubrication analysis reports, and contaminated filling points. In the lubrication strategy, improvements could be included like closed lubrication systems, clearly marked and coded lubricants per point, effective filtration systems, dedicated flushing, clean sampling, dedicated follow-up of lubrication analysis reports, and protection of filling points and closed systems and filling cans.

Safety and Environment

Special administrative processes are generally required for potential environmental damaging products, i.e., collection and disposal of lubricant waste, cleaning rags, spillage of cleaning material, empty packaging and drums, cleaning chemicals, etc. Special safety and environmental arrangements are also required for the storage of lubricants, unless removed from the site after lubrication activities. Spillage reduction, e.g., during relubrication, and its safety and environmental consequences, needs to be addressed by appropriate procedures, training, and tools.

Warehousing and Supply

Various inventory issues may drive desired improvements activities. Identified problem may include high lubricant inventories compared to consumption, many different lubricant types, excessive inventories due to available pack sizes, high lubrication logistics administration cost, aging lubricants in stock and unsuitable for use, and damages packaging due to excessive storage periods. An extensive audit and planning on the lubrication plan for all lubrication points can Lubrication Management improve the situation considerably. Further, an inventory analysis could be done together with the lubricant suppliers. "Total lubrication consolidation is the latest trend in the challenge to reduce overall maintenance costs, extend equipment life, and simplify the lubricant purchasing process. Benefits include: efficiency improvements through better inventory controls, effective preventive maintenance and service options, and improved overall management practices." [2]. Typical lubrication consolidation targets include reduce stock of lubricants, reduce consumption of lubricants, and reduce number of different lubricants on stock.

Lubrication Monitoring

Monitoring the status of the lubrication practices could indicate various problems. For example, repetitive failures dues to inadequate lubrication,no follow-up of lubrication analysis reports, poor maintenance of lubrication systems (dirty points and ineffective pipes), and incorrect lubricants used, lack of reporting processes of the lubrication activities. This can be the reason to improve the preventive maintenance and predictive oil analysis programs, including root cause failure analysis to prevent problems from occurring, and coordination of follow-up on analyses done. [3]. Further improvements include closer monitoring of lubrication systems, clear identification offilling points, and an open lubrication management system for lubrication reports, routes, andanalysis reports.

Maturity Stages

Depending on current lubrication practices, a plant can grow from a "stabilizing" basic requirements stage, lubrication processes implementation stage, a proactive stage with continuous improvements, towards an integrated stage with the overall asset maintenance strategies. Analyzing the current lubrication practices and comparing with targets depending on business objectives, an overall lubrication strategy and roadmap can be derived covering the various activities to improve. As an example mapping and visualization of lubrication strategy components versus maturity stages a matrix like in figure 1 may be applied. [4].

Maintenance Culture & Practice	Lubrication Strategy	Cleanliness and Contamination Control	Data Base Management & Reporting	Lubrication Knowledge & Application	Health, Environmental & Safety	Supply /Storage
Asset Efficiency Culture						
Proactive Lubrication Management						
Lubrication Processes						
Basic Requirement						

Fig1: Lubrication strategy components mapped towards maturity stage (Courtesy of Enluse B.V)

Road map for Lubrication Management –Where, How & What to improve

Lubrication Management is a structured programme designed to help identify the required improvements in lubrication practices of company and to guide towards lubrication optimization leading to maintenance excellence.
Five main steps are defined in the process:

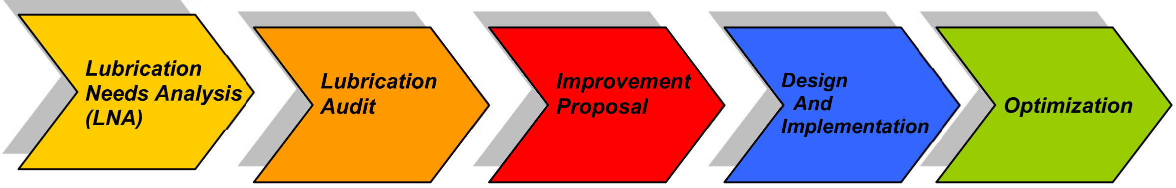


Fig 2: Lubrication Management Road Map

• `**Lubrication Needs Analysis (LNA):** Starting point is to run a first assessment to ascertain main goals and concerns. It will also provide an indication of the maturity level of their current lubrication programme, if any.
In this stage, interview with key responsible managers for lubrication is carried out using structured questionnaire to analyze company's current lubrication performance from four different perspectives – Strategy, Identification, Control & Execution. Answers can be scored from 0 to 4, according with the table 1:

Ring	Maintenance Maturity Level	Comments
0-1	Firefighting or Absent	Requires immediate Action
2	Maintaining	Good Behaviour
3	Promoting	Best Practice
4	Innovating	World Class

Consequently, although this assessment might not provide all the details required to present a sound improvement proposal, it will unveil the lubrication programme maturity level and certainly, main strengths and improvement opportunities.

On the day of performing the assessment, it is crucial that the discussion is not performed solely in an office environment but is complemented with a quick tour through the facility. Such tour will allow validating the given answers with the actual practices in place. As well, it will increase the involvement of technicians, which in the end are the ones dealing on a daily basis with the execution of lubrication activities. The report must highlight findings in the four main blocks of the assessment: Lubrication Strategy, Work Identification, Work Control and Work Execution. [5].

Diagram 1: Spider Chart

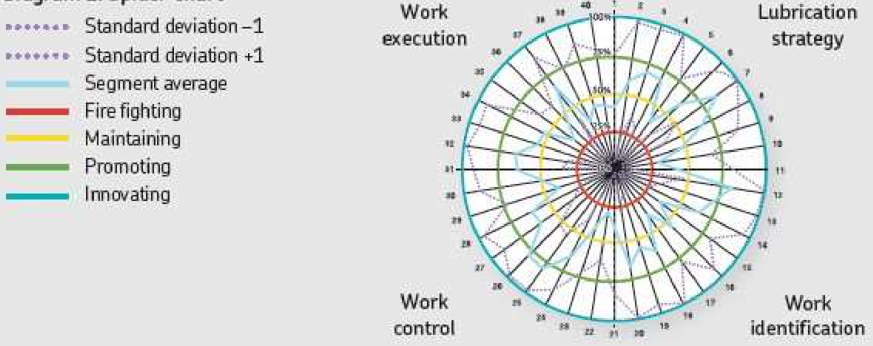


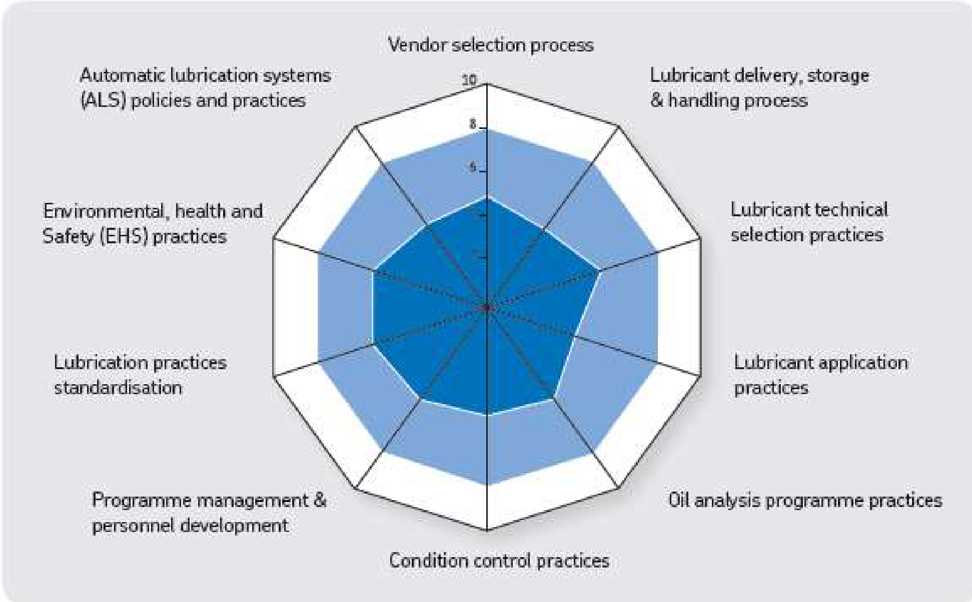
Table 1: Maturity Matrix Summary

The table shows actual overall summary matrix status from 500+ Client Needs Analyses performed by SKF.

Main facet / Maturity	Absent	Fire fighting	Maintaining	Promoting	Innovating	Not applicable	Not understood	Totals
Maintenance Strategy	3,97	5,31	3,51	4,91	6,78	0,38	0,16	25,0
Work Identification	5,6	3,74	2,44	3,39	8,42	1,3	0,12	25,0
Work Control	4,33	2,87	4,41	5,78	6,68	0,83	0,09	25,0
Work Execution	5,02	6,79	3,46	3,61	5,36	0,71	0,06	25,0
Subtotals per choice of response	18,91	18,71	13,82	17,69	17,23	3,21	0,43	100,0

• **Lubrication Audit:** The second step is to evaluate their underlying weaknesses. The output will be a comprehensive report of their lubrication programme and its efficiency. It also forms the basis of an action plan.

SKF Lubrication Audit is a thorough assessment, comprised of 267 questions divided in ten sections according with major components of a lubrication programme as depicted below. It is required that all the team involved in lubrication planning, execution and evaluation takes part of this assessment, for they all can provide useful insight about actual lubrication programme. This assessment must provide all required information for the third step of the Lubrication Management process: the "Improvement proposal". [6].



Improvement proposal: Once a complete diagnosis has been established and improvement opportunities have been defined, the third step is to formulate specific activity plan. Typically, such plan is a combination of strategic planning, training, equipment, technology and activities[8].

The improvement proposal must contain key findings, main strengths, improvement opportunitiesfound, potential savings calculation and specific suggestions/recommendations.

• **Design and Implementation**: The fourth step is to design and implement the action plan and its activities, as described in the improvement proposal presented in the previous step.

It is important that the appropriate resources are allocated and developed in local units in the short – medium term in order to speed up the effectiveness of the programme. In the meantime, the team behind the lubrication management support database will provide you the help required to develop those local capabilities.

• **Optimisation**: Key performance indicators and subsequent assessments will provide the required insights into keeping a constant improvement pace. Any improvement process will require Key performance indicators measurements to verify its effectiveness. By means of them or by means of performing new assessments, the improvements will be measure

Moreover, at this stage if the company is satisfied with the achievements, those improvement proposals left in stand by, or even new ones will normally be considered. [9 & 10].

Case Study: Lubrication Management Program @ Hindalco, Belgaum

Statement Problem:

To evaluate the current lube practices across the plant to ascertain;

- Curent lubrication practices (relubrication quantity & intervals)
- Suitability of current grease used.
- Cost benefit analysis of the proposed solutions (Adopting SKF standard grease & proposed interval/quantity)
- Bearing failure rate & hence downtime cost.

Achieved Benefits:

- Establishing industry standard lubrication practices at shop floor
- Reeducation in grease consumption & hence overall maintenance cost
- improved performance of equipments with standards grease
- Training of employee on industry standard lubrication practices
- Reduction in bearing failure & downtime
- Overall reduction in lubrication cost
-

Estimation of saving – Reduction in Grease consumption

Department	Before Lube Managment		After Lube managment		Savings (Approx)
	Grease	Consumption /month(In kgs)	Grease	Consumption/ month(In kgs)	
Bauxite Digester/Grinding	L1	94.5	X1	70.87	**25%**
Calcination	L2	15.75	X2	12.6	**20%**
Precipitator	L3	18	X3	10	**22%**
Mud Thickener	L4	54	X4	44.28	**18%**
Lime Building & Vanadium Oxalate	L5	42.75	X5	36.33	**15%**

Road MaP - Implementation Plan

	Activity	Proposed Date	Status
1	Forming a competent team involving representatives all the departments of HINDALCO.	April 1st ,2010	Completed
2	Identify & list the departments/equipments to be taken upfor the project.	April 1st ,2010	Completed
3	List the bearing number/rpm/temp/lubricant in use for eachequipment through survey or by referring maintenance Records	April 26 -29th 2010	Completed
4	Interaction with maintenance team to collect details on relubrication quantity/interval.	3rd to 5th May'2010.	Completed
5	Estimation & Implementation of the right grease, relubrication interval & quantity.	10th to 17th, 2010	Completed
6	Analysis of the results thus obtained to measure the savings	May 20th, 2010	Completed
7	Implementation of the findings at least in one department	October 15th,2010	Completed
8	Review of the performance	January 15th,2011	Completed
9	Extension of the program to other departments	March 1st,2011	Completed

Conclusion

Evidence of the lack of precision in greasing bearings can be quite easily in almost any industry facility. Hot running bearings, grease contaminated motor windings, piles of grease around machine mounting components and of course, poor component life provides evidence of over greasing, by far the most prevalent greasing problem in plants

Lubrication Management programme can be defined as the sum of all the activities performed ina given facility to ensure the right lubricant is provided in the right quantity to the right point at the right tie with the right method.

With the implementation of Lubrication Management, improvements are typically found in areas like - Lubrication strategy, Process and practices, Documentation, Lubricant assortment and supplies, Storage and handling, Planning and scheduling, Data management and reporting contamination control, Waste handling, Environmental, healh & safety (EHS).

References

[1] David C. Lubricants 101 - Fundamentals of Lubrication, 2003.
http://www.aptitudexchange.com/ax/content/item.jsp?id=NC_03_Lub101
[2] Stuttelburg, Jim. Lubrication Consolidation, 2003.
http://www.aptitudexchange.com/ax/content/item.jsp?id=NC_03_ConsolLub
[3] SKF General Catalogue, Publication 5000 E. 2003.
[4] SKF Bearing Installation and Maintenance Guide, Publication 140-710. 2000.
[5] SKF, Bearing Lubrication; An Introduction to Oil and Grease Lubrication of Rolling Element Bearings. 2002.
[6] Schram, Gerard. LubeSelect; A Bearing Lubrication Advisory System. April, 2002.
[7] Cartwright, Steve. Selecting the proper Lubrication System for your plant. 2003.

http://www.aptitudexchange.com/ax/content/item.jsp?id=NC_03_LubPlant
[8] Godin, Frank, and Kopschinsky, Jay. Best Practices for Lubricant Storage and Handling. 1999.
[9] Herguth, William. Lubrication Acceptance and Evaluation; Testing and evaluation of Lubricants from Laboratory Lubrication Management Perspective. Herguth Laboratories, Inc. 2003..
[10] Johnson, Doug and Herguth, William. Lubricant Monitoring and Analysis; An overview of Lubricant Monitoring Methods and Processes. SKF Reliability Systems and Hergurth Laboratories, Inc., 2002

Guide Rope Lubrication – A case study in UCIL's Jaduguda Mine

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Abstract

The failure of a steel wire rope while in service is potentially disastrous, particularly as part of a winding system transporting a large number of people down a deep mine through a vertical shaft. The paper explains the functions and use of the wire ropes which guide the mine conveyances and delves upon a critical aspect of the maintenance of such wire ropes – lubrication. A case study of such ropes explaining their criticality, factors in lubricant selection and other facets of lubricating guide ropes faced in Jaduguda mine of Uranium Corporation of India Ltd, one of the deepest metal mines of the country, is explained.

Introduction

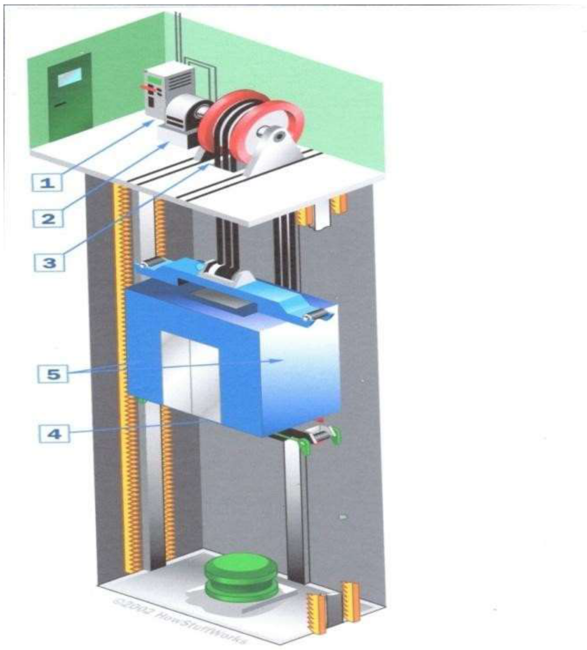
In underground mines, the mine shaft, its winding installation and conveyances, constitute the most critical transfer facility, transporting both men and materials deep into the ground. With the entire workforce to be daily transported by this form of transport, it is obvious that shaft winding installations must be constructed, operated and maintained with the highest standards of safety. In order to ensure and continually maintain high safety standards, all the components of the winding system i.e. the winding mechanism, controls, signaling systems, pipes, shaft guides for the conveyances and probably the most important aspect – the various steel wire ropes, require to be maintained optimally as any laxity can prove to be calamitous.The failure of a steel wire rope while in service is potentially disastrous, particularly if it is part of a winding system transporting a large number of people down a deep mine through a vertical shaft. Even when not transporting people or material, a rope failure can give rise to significant risks to people working near the shaft. A rope failure can cause damage to winding equipment and the shaft itself putting it out of action which apart from resulting in very hazardous recovery operations can present severe risk to many lives below ground. The present paper speaks of the function and use of the wire ropes which guide the mine conveyances and delves upon a critical aspect of the maintenance of such wire ropes – lubrication.

A case study of such ropes covering their criticality, factors in lubricant selection and other significant facets of lubricating guide ropes is explained in the Jaduguda mine of Uranium Corporation of India Ltd, one of the deepest metal mines of India. However before we go into the details of mine conveyances and ropes, it is felt prudent to explain a mine conveyance with regard to a mine shaft, especially to those not familiar with mining.

Elevator versus Mine Winder

The closest analogy of a mine conveyance is the residential or commercial elevator (also called a lift) used by everyone. We all know that an elevator is basically an equipment used for vertical transportation, that moves people or goods to different heights (levels, floors) of a building or any high structure. These elevators move in specially constructed well like openings going all the way from the ground floor (or basement) till the top of the building. A simple elevator is shown in the block diagram below.

Block diagram of an elevator



In most elevators, the passenger compartment (cabin or car) is raised and lowered by steel traction ropes. The ropes are attached to the elevator car and looped around a sheave **(**3**)**. A sheave is just a pulley with grooves around the circumference. The sheave grips the hoist ropes, which when rotated makes the ropes move. The sheave is connected to an electric motor **(**2**)**. When the motor rotates one way, the sheave raises the elevator and when the motor turns the other way, the sheave lowers the elevator. The sheave, the motor and the control system **(**1**)** are all mostly housed in a machine room located above the elevator shaft. The ropes that lift the car are also connected to a counterweight **(4)**, which hangs on the other side of the sheave. The counterweight weighs about the same as the car filled to about 40% capacity. Thus, when the car is 40% full, the counterweight and the car are in a balanced state. The purpose of this balance is to conserve energy. With equal loads on each side of the sheave, it only takes a little bit of force to tip the balance one way or the other. Basically, the motor only has to overcome friction, with the weight on the other side doing most of the work. Both the elevator car and the counterweight ride on rigid guide rails (5) along the sides of the elevator shaft. The rails keep the car and counterweight from swaying back and forth and they also help the safety systems to stop the car in an emergency.

Winders in mines are also fundamentally elevators which hoist and lower men, mineral and materials into and out of the mine by the same principle. The main difference is that mine conveyances are normally bigger, more rugged and travel much deeper into the ground with heavier loads and at higher speeds. A mine shaft can be envisaged as an elevator well in reverse, going hundreds of meters into the ground.

Wire ropes used in Mines

In order to understand the lubrication aspects of guide ropes, a brief understanding of wire ropes is necessary. Wire ropes used in vertical mine shafts have to be both strong enough to do the work required and also have specific properties to match the conditions in which they will operate.

A wire rope is just like a working machine made up of many moving parts. As such, like any machine, a wire rope also requires consistent maintenance and proper care in order to remain in good condition to be functionally efficient. A mine shaft rope consists of many individual wires laid into a number of strands which in turn are laid round a central core to form a rope having one straight strand. The type and size of wires used, the number of wires in the strands, the type of core and the rope construction determine the characteristics and strength of a wire rope for any given diameter and thus determine the application for which it is suitable.

Wire ropes should have the following properties: Tensile strength i.e. the strength necessary to withstand a certain maximum load applied to the rope. It includes a reserve of strength measured by factor of safety. Crushing Strength is the strength necessary to resist the compressive and squeezing forces that distort the cross section of a wire rope, as it runs over sheaves or hoist drums under heavy load. Fatigue resistance is the ability to withstand the constant bending and flexing of a wire rope that runs continuously over sheaves or hoist drums. Fatigue resistance is more important when the wire rope must be run at high speeds as constant and rapid bending of the rope can break individual wires in the strands. Abrasion Resistance is the ability to withstand the gradual wearing away of the outer metal, as the rope runs across sheaves and hoist drums. The rate of abrasion depends mainly on the load carried by the rope and the running speed. Generally, abrasion resistance in a rope depends on the size of the individual outer wires.

The standard method of denoting the construction of a rope is to quote its type, the number of strands, number of wires per strand, construction of strand, direction and type of lay and the type of rope core. For example, the construction of the guide rope used in Jaduguda Mines is ‘Half Lock having a strand construction of 11+11/8-8-1, RH meaning that it is a round strand rope having a central steel wire core on which two strands of 8 wires each are wrapped. On top of this combination two more strands of 11 wires each are wrapped from either end. Being a half locked rope the top wires are alternately rod and rail shaped. Thus the total numbers of wires are 11+11+8+8 = 38 plus one central core wire.

To reduce corrosion and friction between wires, the wires and its core must be thoroughly lubricated during manufacture. The amount and type of lubricant should be based upon the rope duty. For guide ropes, being stationary, the lubricant used is only to prevent rust and

corrosion and also helps in maintaining its rigidity.
Since guide ropes are stationary ropes hanging in the shaft and not bending round pulleys, they do not need to be as flexible as other ropes. Therefore they are made of large wires to withstand the wear of conveyance shoes. Guide ropes are always of half-locked coil construction since this gives a smooth rope surface, increased strength and excellent locking properties.
Guide ropes are at least of 29 mm in diameter going up till 46mm. The rope size depends on the depth of the shaft, the applied tension and the safety factor. The nominal tension is usually of the order of 3 tonne + 0.5 tonne/100m of rope length.

Maintenance of guide ropes

The main aspects of rope maintenance are lubrication, preventive maintenance and repair/ renewal. Rope repairs should only be carried out by trained personnel, competent to do the job. During operation the wire strands that make up a wire rope are under constant stress and strain. The strands constantly rub against one another causing friction. The friction cause strands to wear and the friction heat causes oxidation resulting in high internal core temperatures which accelerates rusting and causes premature rope failure.

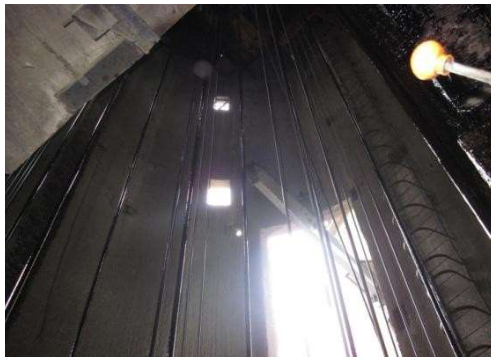
Wire ropes are affected by heat, corrosion, fatigue or any other damages. The resultant effects are extension of strands, loss of surface metal, potential internal ruptures due to heat, loss of shape of rope and hence more friction losses. Some ropes may also deteriorate as a result of surface embrittlement, either due to heavy pressure causing plastic deformation or by the rope rubbing heavily against metallic obstructions causing martensite.

Although most wire ropes are lubricated during the wire rope manufacturing process, but the lubricant does not last the life of the rope. One should always choose a lubricant that contains no acids or alkalis, possesses the adhesive strength to stay on the rope, penetrates between wires and strands, has high fluid film strength, resists oxidation and remains pliable. It is important to remember that most wire ropes fail from the inside out. Proper lubrication helps to prevent deterioration of wire rope due to rust and corrosion. The two KPI's to look for in a wire rope lubricant are wear resistance and corrosion prevention.

Challenges in guide rope lubrication – a case study in UCIL

Uranium Corporation of India Ltd (UCIL) – an Indian Public Sector Enterprise under the Department of Atomic Energy, was the first organization in the country to procure two friction winders, for its underground uranium mine at Jaduguda – a small densely foliaged hamlet, in the eastern state Jharkhand. The winders were procured from ASEA AB Sweden with a cage winder for transportation of men and materials and the other was a skip winder for the hoisting of uranium ore from the underground mine. The winding system comprising of the motors, gearboxes, drums, brakes and other controls were housed in a 7.5 metre diameter and 46 metre high concrete tower (headframe) exactly above the 5 meter diameter mine shaft. All the wire ropes for the winding system was supplied by M/s Whitecross, UK. As the rope manufacturer had also supplied some drums of guide rope lubricant and had his service engineer posted for a few months for other installations, the initial phase passed off smoothly.

Jaduguda Mine Headframe



Wire ropes in Jaduguda Mine shaft

In the following year as the available lubricant levels diminished and the service personnel left, the selection and application of the high viscosity lubricant became a big challenge. A total of eight numbers of 41mm diameter half locked guide ropes of approximately 680 metre length, with the top ends clamped on the surface headframe 42 metres above ground and the other end tensioned by application of weights at depths of 635 metres close to the shaft bottom had to be lubricated.

41mm Guide rope clamped in headframe

Guide ropes

Moreover unlike the top winding ropes which travelled and could be lubricated from a specific location in their path of travel, guide ropes were stationary and being constantly hung in the mine shaft were continually exposed to dust, water, heat and often small ore chips which spilled during unloading – thus posing challenges we had never faced earlier. The first major challenge - selecting the proper lubricant.

With an inbuilt sense of complacency coupled with innate procrastination we finally began our process of searching for suitable indigenous lubricants when the requirement became almost critical. The first step was to assess the properties required from the lubricant for our stationary guide ropes suspended in our mine shaft in varying environmental conditions. After detailed study of the application we came to the following conclusions regarding the properties to look for in the lubricant:

a) the lubricant should adhere firmly to the wires and be viscous enough to resist gravitational forces as the ropes hang vertically.
b) must also have water-repellent properties to protect internal and external surfaces from corrosion
c) should not deteriorate with age, exposure or temperature changes, e.g. by hardening or

cracking.

d) The selected lubricant must be non-corrosive and stable over the range of temperatures and environmental conditions likely to be encountered and should not give rise to any by-products which could attack the metal strands.

Next we studied the possible causes which could cause the deterioration of guide ropes. Two major reasons surfaced: corrosion and abrasion. It was evident that corrosion could cause shortened rope life due to metal loss, pitting and stress risers from pitting. Thus proper and adequate lubricant application in field conditions was the only way to reduce corrosive attack on the guide rope.

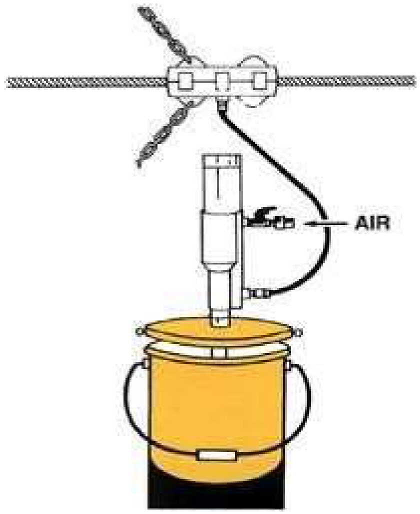
Studies revealed that in guide ropes abrasive wear occurs on the inside and outside of the ropes. The outside of the rope accumulates dirt and contaminants from the shaft environment. This causes three- body abrasive wear(i.e. foreign hard particles trapped between two sliding surfaces and abrading one or both surfaces or embedded in a softer surface and abrading the opposing one), which erodes the outer wires and strands. Abrasive wear could reduce the rope diameter and result in core failure and internal wire breakage. The solution was to apply wire rope lubricants having penetrating properties to reduce abrasive wear inside the rope and also wash off the external surfaces to remove contaminants and dirt.

With all the above information detailed discussions were held with technical representatives of two leading Indian oil companies. After understanding our requirement and visiting the site they took samples of the lubricant then being applied. After a few weeks one company suggested the use of a heavy duty grease while the other proposed usage of a heavy bodied, adhesive type black lubricant then being mostly used for open gears. Samples were supplied by both the companies and the respective lubricant was applied on different ropes. While the application of the heavy duty grease was comparatively easy but it was found that within a few days some areas of the rope were exposed with the grease having been washed off. In the second case however while the high viscous and tackability properties made application rather difficult but even after six weeks the lubricant had largely retained its location with only a minimal amount of downward travel. A small sample of this used lubricant was scraped off the rope and given to the party for testing. Test results revealed only marginal differences in kinematic viscosity and specific gravity and external dust particles just clinging on to the surface with hardly any internal ingress. This lubricant was procured, applied on all the 8 guide ropes and kept under close visual inspection. With no negative fallouts, over a period of time this lubricant has become our standard lube for guide ropes. The lubricant is a heavy bodied, adhesive type black bitumen based lubricant which (as per data sheets) has been formulated using extremely refined steam cylinder oils having excellent thermal and chemical stability. It has a kinematic viscosity between 200-250 cSt at 40 ^{0}C. The bituminous component has been providing a long lasting lubricating film and excellent adhesiveness with minimal lubricant throw off. The lubricant's adhesive property has resulted in applications in small quantities thus actually reducing lubrication cost. This lube has also protected the guide ropes against rusting and has provided effective resistance against water, which drips in the shaft.

The second major challenge - selecting the proper method of application :

The proper and even application of high viscosity lubricants on guide rope is a problem being faced in all deep mines. In UCIL over the years some mechanical methods of application have been tried out. A short write-up on a mechanical method tried out a few years ago is explained and the reason why it had to be abandoned. The system (shown below) comprised of a high pressure air pump with flow controlling valve, ball valve, drum cover, flow control value, follower plate, flexible hoses, lubricating chamber and anchoring chains. The air supply to the pump had to be atleast 8 bar. Split seals were fitted around the rope and clamped in placed by the two halves of the lubricating chamber.

The unit was anchored by two chains to some stationary object. The pump was started and the wire rope was to be pulled through the Lubricator.



The lubricant under high pressure penetrated, cleaned and lubricated the wire rope but it was noticed that in order to obtain total penetration through the rope the pressure required was actually much higher, around 20 bar in the chamber.

The reasons for the failure of this system for lubricating guide ropes were as follows:

1. In this system the rope had to be pulled through the lubricator for lubrication to take place. This was not possible in case of guide ropes which were fixed and stationary. Arrangement was thus made to work the system in reverse i.e. equipment was kept on the top of the conveyance with the seals clamped to the adjoining guide ropes and the conveyance was made to move downwards or upwards. This method was only possible till a few metres from the ground level as with the compressors being located on the surface, it was impossible to supply compressed air to the pump due to hose length restrictions.

2. With such high pressures being encountered it became a potential risk for persons standing on the mine conveyance very close to the machine in a restricted area and operating the lubricator.

Thus in spite of the general assumption that lubricating with the aid of brushes, rags, gloves or by other means is costly, risky and ineffective, the proven good old ‘hand application’ method has still proved to be the most convenient in UCIL. If the rope is dirty or has accumulated layers of hardened lubricant or other contaminants, it is cleaned with a wire brush and petroleum solvent before re- lubrication. The wire rope is then dried and lubricated immediately to prevent rusting.

Precautions while lubricating guide ropes

Although the guide rope lubricant does not contain any hazardous ingredients but mild eye and skin irritations have been observed at times. As such all personnel involved in lubrication wear nitrile rubber gloves, aprons, rubber shoes and goggles (although due to humid underground conditions these have to be occasionally cleaned as they become very hazy due to fogging). Lubrication is carried out by at least two persons on a rotational basis who are advised to take occasional short interval breaks at a fresh air base.

Conclusion

Proper lubrication of guide ropes can thus result in the long life of guide ropes and prevent unforeseen problems, provided that correct maintenance practices are followed and the correct

lubricant is used. It is important to bear in mind that guide ropes, unless properly protected against oxidation can corrode fast, resulting in fatigue failures which in turn may lead to a major catastrophe.

References

1. American Iron and Steel Institute. (1985). Wire Rope Users Manual, Second Edition.
2. CRC Handbook of Lubrication, (1983). Volume 1.
3. Brewer, A. (1974). Effective Lubrication.
4. Lube data sheets.