Tribology and Lubrication in Extreme Environments
(Two Case Studies)

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Abstract:
Technological advances in metallurgy, ceramics, nano, and biomaterials, etc. are challenging the physical and chemical limits of traditional lubricants. Strict new environmental regulations have directed industry to reduce the demand on limited natural resources, reduce industrial waste and minimize hazardous emissions. Simultaneously, the development of new world markets has led to the mechanization of millions of new processes essential to the manufacturing efficiency of a global marketplace. This paradox, in and of itself, has presented a challenge to the lubricant production industry. On the one side, there are more systems that require lubrication and, on the other side, consumption must be reduced.

Introduction:

The first challenge in addressing the topic of '*Tribology and Lubrication in Extreme Environments'* is to define what an *Extreme Environment* is. For the purpose of this paper, *Extreme Environment* will include any device and/or system requiring a lubricant operating under any of the following conditions:

- beyond the original machinery design specifications
- beyond the original machinery ambient parameters
- application in an environmentally sensitive location
- beyond the original lubricant design specifications

Global competition and demand for higher shareholder profits has forced Industry to reduce operating costs while increasing productivity. The most common way to increase productivity and cut costs is to ramp-up existing machinery and equipment above and beyond their optimum design limits. Consequently, machinery is running at faster speeds and at hotter temperatures. This imparts undue stress on the lubricant by demanding increased performance and heat dissipation that the product's inherent chemistry does not allow.
Another scenario involves the physical location of operating equipment in sensitive environmental areas. This may severely limit the choice of traditional lubricants and lubrication techniques as the ecological properties of candidate fluids take precedent over lubricant performance properties. Simultaneously and conversely, increased demands on the chemical and petroleum industries to engineer materials that are environmentally safe and friendly inherently limit the application range of these products.
One must realise that demands, regulations and obligations about the environmental, ecological, and disposal issues must be met and dealt with while continuing to produce competitive products.
As a lubricant producer, not only must one have to address the increased performance demand but, also the environmental impact of one's products by analysing their entire life-cycle characteristics.
Today, waste disposal costs normally supersede initial lubricant purchase prices. To cost an effective lubricant on any piece of machinery or equipment encompasses not only the initial purchase price, but also incorporates the degree of energy efficiency, performance, waste, internal re-use, product recycle-ability, and final disposal considerations.

The marriage of all this forms the basis of modern lubrication technology and the foundation of tribology and lubrication research for future applications.

Methodology and Analytical Concepts:

Traditional oil test procedures have proven that with proper monitoring and regular lubricant change-over intervals, machinery, operating equipment, and lubricant life may be significantly extended [1]. New analytical and sensor technologies permits instant on-site evaluation of lubrication performance and allow external or automatic intervention to enhance and prolong the optimum performance level of a lubricant. Advances in machinery vibration detection, fluid management control through proper proactive maintenance, and personnel education programs have collectively contributed to lubricant life extension. More recently however, the desire to attain *ISO 14000* certification necessitates the implementation of a comprehensive Fluid Condition Monitoring and Management program.

In *Extreme Environment* applications, fluid degradation or contamination is usually premature. This alone can result in untimely machinery breakdown as *undetected* additive depletion and/or contamination will cause catastrophic failure (Fig. 1). In most cases, the direct cost of failure of a flawed fluid management program far outweighs the indirect 'cost savings' of a successful one.

Tribology and Lubrication in *Extreme Environments* necessitates the planning and implementation of a Condition Monitoring program. A cooperative liaison must be established between the fluid producer, the laboratory, and the end user. A line of direct communication between parties must be open and synergetic. Once this liaison is established, the desired goals must be identified and agreed upon.

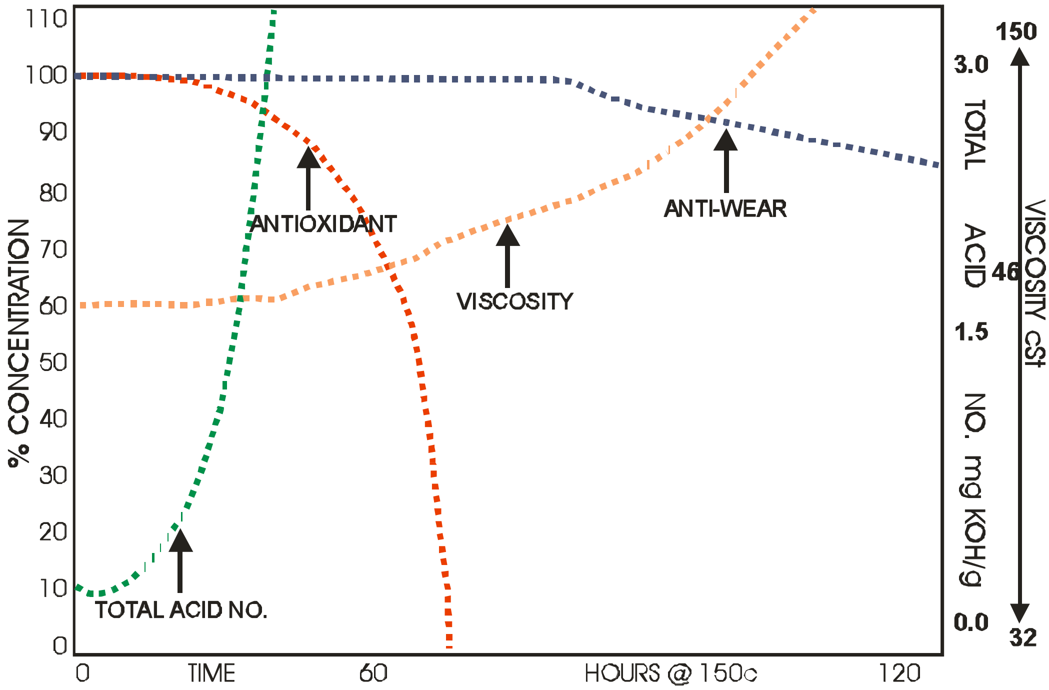

Fig.1

Fig. 1 *Shows a typical lubricant degradation over time. In this case, an ISO 46 (orange line) anti-wear hydraulic fluid was operating at 150°C. Initial antioxidant and anti-wear levels were at 100% in the 'new' oil (red and blue lines respectively). The originating TAN (Total Acid Number) was 0.2 KOH/mg (green line). As the fluid is stressed in operation a depletion in antioxidant after only 30 hours of operation causes a significant increase in AN therefore increasing the fluid viscosity and resulting in premature lubricant failure.*

Metallurgical alloys used in bearings, and gears, etc., are assembled and tested at specific operating speeds and temperatures (Fig.2). At elevated speeds and temperatures, these alloys will deform and expand in unpredictable and non-reproducible dimensions (Fig. 3). These deformations will normally reduce clearances allowed for lubrication and change spherical rotation to 'erratic'. This in itself starves the lubrication points, generating more heat, more deformation, increased vibration, and finally failure.

Fig.2
Various types of bearings used in industry

Fig.3
Ball bearings exposed to heat levels beyond their original design. Note how they lost their spherical form and created scuff marks on the surface by due to sliding.

Chemical effects can also force premature additive degradation (Fig.4) and cause machinery failure [2].

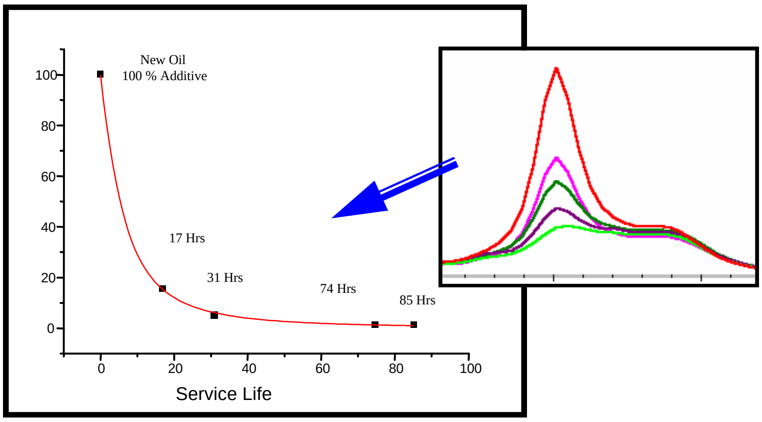

Fig. 4 *Box on the right shows how using FT-IR spectroscopic analysis depicts premature additive degradation due to a chemical reaction with the antioxidant and alumina dust found in an aluminum smelter. This superimposed degradation is then transposed to the curve in the box on the left.*

Case Study #1: Optimizing the Performance of an 'Industrial' Diesel Engine Oil Formulation for Operating Mobile Equipment (*Caterpillar V225B with a Caterpillar 3208 motor*) in an Aluminum Smelter.

These heavy-duty vehicles operate in a high-temperature, dusty environment located next to aluminum melting pots.
Preliminary tests on mineral-based oils traditionally used by the facility showed premature oxidation and increased viscosity in the motor oils. FT-IR analysis showed a quick, distinct reduction in performance additives, particularly the antioxidant (Fig 4 above). The end user reported that the life-span of these fluids never surpassed 75 hours of use and that the engines had to be rebuilt every 9 to 12 months.
After forming a cooperative liaison with the smelter and our own analytical laboratory and lubricant production facility, a 'loop-back' information flow was instituted. This entailed:

a) proper representative fluid sample retrieval
b) timely acquisition
c) analytical testing
d) formulation revision
e) product replacement

FTIR spectroscopy data collected over a period of time proved that airborne alumina dust (Al_2O_3) caused a chemical degradation of the performance additive package, in particular, the antioxidant (Fig 5).

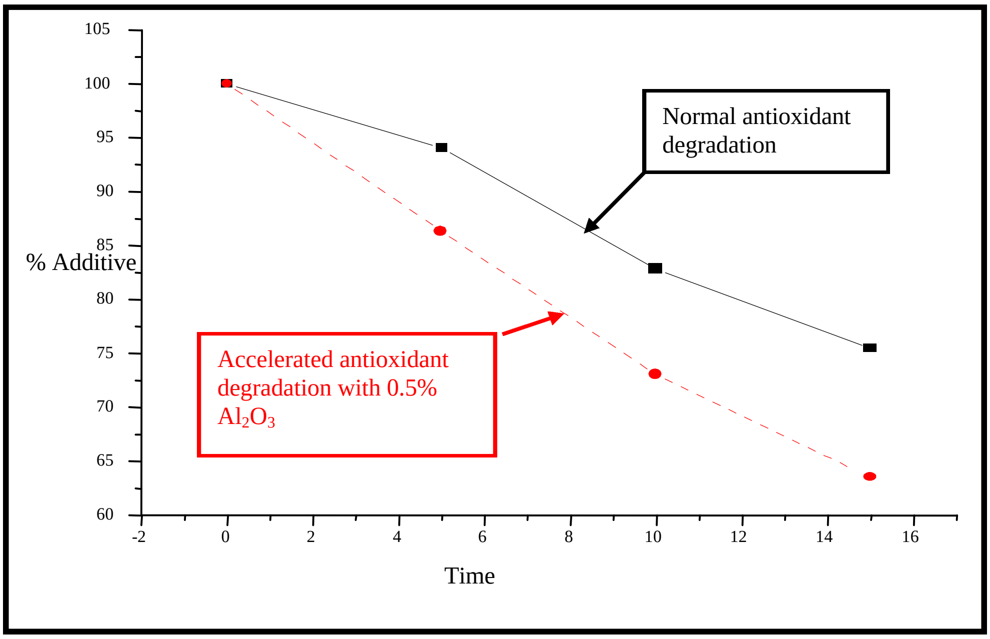

Fig. 5 *Depicts the antioxidant degradation slopes of the SAE 15W40 Engine oil:*
Red curve: in the presence of Al_2O_3
Black curve: without the presence of Al_2O_3

A stable semi-synthetic base-stock was chosen (PAO/mineral), and was formulated with an antioxidant specifically developed to resist chemical degradation (fig. 6). The cooperative liaison between the lubricant supplier, lab, and customer provided the lubricant manufacturer with enough time and analytical data to formulate a product specific to the application. From the customer side, the new lubricant resulted in prolonged oil change intervals (increasing from 75 hours to 200 hours) therefore reducing fluid consumption as well as disposal costs. Furthermore the service life of the vehicles increased from an average of 9-12 months to more than 3 years of continuous operation.

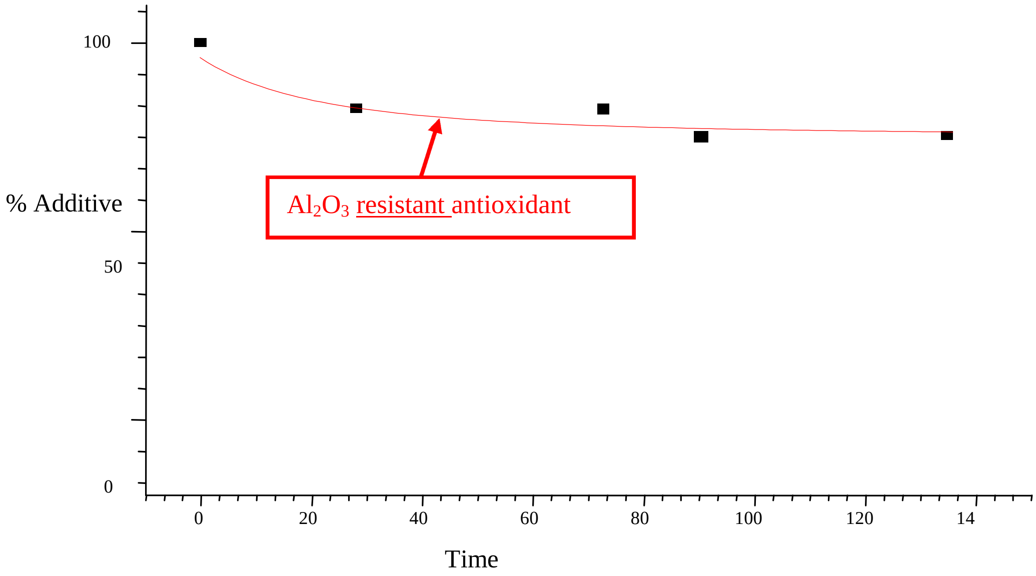

Fig. 6 *Depicts the antioxidant degradation slope of the SAE 15W40 Engine oil with a modified antioxidant resistant to Al_2O_3.*

Case Study #2: Performance Optimization of Industrial Equipment at a Copper Mine in Northern Canada.

Moving lubricants in and out of a subterranean mine is a costly and cumbersome endeavor. Inherent safety issues come into play as critical equipment such as air compressors and sump pumps must work continuously at optimum efficiency. At this particular facility, ambient temperatures ranged from -50°C to +40°C.

Again, a working liaison was established with the customer. Specific goals were proposed, discussed, and agreed upon as follows:

- To develop superior compressor, gearbox, and hydraulic fluids used in the mining operations.
- To develop an Oil Condition Monitoring program that would ultimately extend engine life as well as re-lubrication intervals.

Three specially designed synthetic fluids were formulated with a relatively high Viscosity Index so they can be used outdoors all year long. The target set and agreed upon for the operation life of these lubricants was 12000 hours. (Below this amount, the fluids would not be cost-effective).
The machinery operates in *Extreme Environments*. In addition to wide fluctuations in temperature, tough environmental laws render lubricant disposal very costly. Fluid handling in and out of a subterranean mine is also cumbersome and a major safety consideration.
Fluid degradation as depicted in Fig. 1 above is inevitable. To counter this deterioration, an aggressive lubricant sampling program was established and degradation curves were tracked for each piece of equipment. Minimum additive levels were determined and were dosed back into the lubricant *in-situ* as needed (Fig. 7) [3-7].

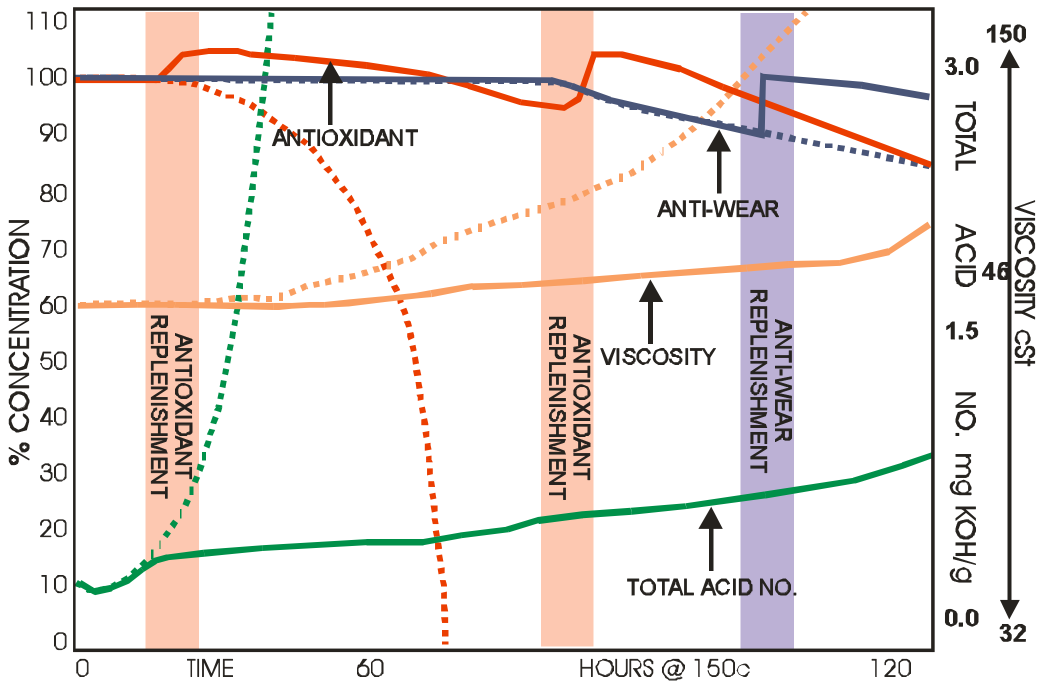

Fig. 7 *Is the same typical fluid degradation graph as Fig 1 except that the antioxidant was replenished at two different intervals and the anti-wear was replenished once.*
As a result of the first antioxidant replenishment the TAN stabilized and therefore kept the viscosity from increasing. This was repeated a second time as the antioxidant reached its minimal level again.
The same was done for the anti-wear additive as its level reached minimum tolerance.

The results were quite definitive. Figures 8, 9, and 10 compare the overall service life of three synthetic fluids compared to their original mineral-based counterparts.

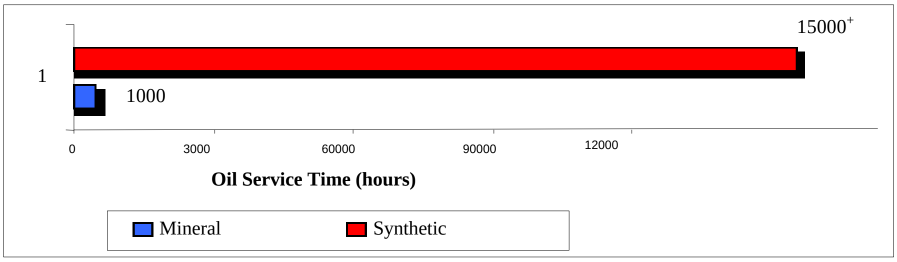

Fig. 8 (Compressor Lube)

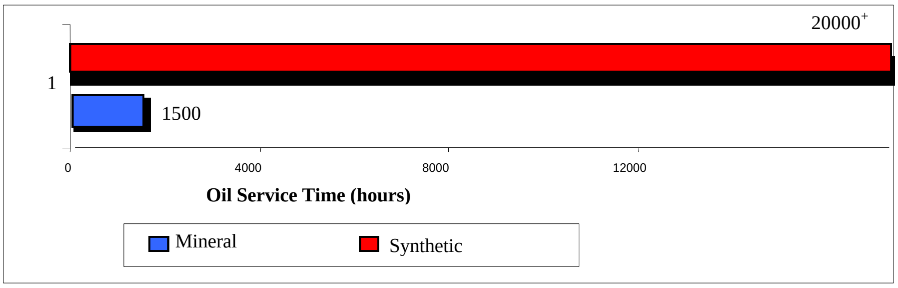

Fig. 9 (Hydraulic Oil)

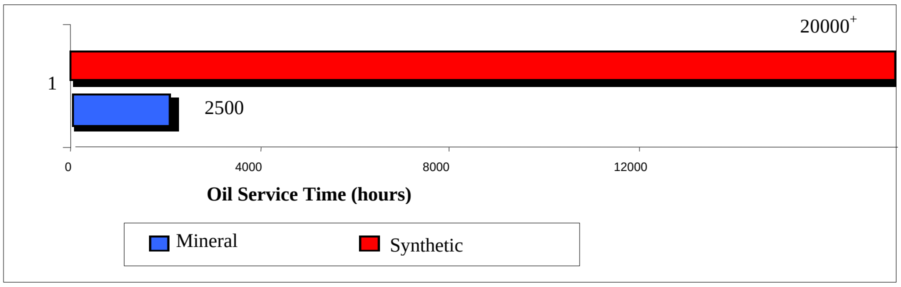

Fig. 10 (Gear Lube)

Conclusion:

There is little doubt that lubricants operating in *Extreme Environments* require a collaborative Conditioning Monitoring program to be effective. Technological advances in metallurgy, lubricants, and composites are still in their embryonic stage. Advancements in one field pose new challenges to the others. Communication and collaboration is mandatory in these applications as there is an inherent dependency on all contributing aspects.

References:

1. Y. Kimura. Tribology as a maintenance tool. In New Directions in Tribology; World Tribology Congress: I.M. Hutchings Editor, London 1977 pp299-308

2. D.M. Haaland and E.V. Thomas. Partial least-square methods for spectral analysis. 1. Relation to other quantitative calibration methods and the extraction of qualitative information. *Anal. Chem.* 1988, 60, pp1193-1202.

3. van de Voort, F.R., Pinchuk, D. and Pinchuk J. Quantitative condition monitoring - Analytical wave of the future? Proceedings of the Society of Tribologists and Lubrication Engineers Condition Monitoring Conference (2001). Paper #7 CD ROM.

4. van de Voort, F.R. and Pinchuk, D. (2000) Quantitative condition monitoring by FTIR spectroscopy. In Proceedings of the 1st 2000 AIMETA International Tribology Conference, September 20-22, L' Aquila, Italy. Edited by Bassini, R., Raparelli, T. and Vatta, F. pp. 328-335

5. Dong, J., Ismail, A.A., and van de Voort, F.R. A novel method to determine TAN, TBN and moisture using FTIR spectroscopy. Technology Showcase 2000, JOAP International Condition Monitoring Conference. G.R. Humphrey, R.W. Martin and T.A. Yarborough. JAOP-TSC 85 Millington Avenue, Pensecola FL. 2000.

6. Dong, J., van de Voort, F.R., Yaylayan, V. and Ismail, A.A. (2000). A new approach to the determination of moisture in hydrocarbon lubricating oils by mid-FTIR spectroscopy. Journal of the Society of Tribologists and Lubrication Engineers 56:11 pp. 30-37.