Energy Efficient Industrial Gear Lubricants

An effort to help the industrial sector manage the projected demand through the use of energy efficient synthetic gear lubricants, which would maximize the energy available to meet demand.

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THE USE OF ENERGY HAS PROPELLED THE WORLD FROM EARLIEST CIVILIZATIONS, THROUGH THE INDUSTRIAL REVOLUTION, TO THE CURRENT TECHNOLOGY ENABLED WORLD. IT ALLOWS US TO HEAT AND COOL OUR HOMES, TRAVEL TO AND FROM WORK, AND UTILIZE THE MULTITUDE OF MANUFACTURED GOODS WE RELY ON. GLOBAL ENERGY DEMAND IS PREDICTED TO BE ABOUT 30 PERCENT HIGHER IN 2040 COMPARED TO 2010, WITH THE INDUSTRIAL SECTOR CONSUMING ALMOST 48% OF THE DEMAND [2]. SEE FIGURE 1.

THE PURPOSE OF THIS ARTICLE IS TO HELP THE INDUSTRIAL SECTOR MANAGE THE PROJECTED DEMAND THROUGH THE USE OF ENERGY EFFICIENT SYNTHETIC GEAR LUBRICANTS, WHICH WOULD MAXIMIZE THE ENERGY AVAILABLE TO MEET DEMAND.

SUSTAINABILITY

Advanced synthetic lubricants can address help us address energy demand to achieve sustainability. ExxonMobil Corporation defines sustainability as balancing economic growth, social development and environmental protection so that future generations are not compromised by actions taken today [3]. See Figure 2. For example, oil that extends lubricant drain intervals may contribute to health and safety by reducing the amount of interaction between humans and the machines. The choice of proper lubricant can also help extend equipment life enhancing reliability and equipment availability leading to increased return on capital or economic growth. And longer oil life can also help reduce waste or environmental impact related to energy use.

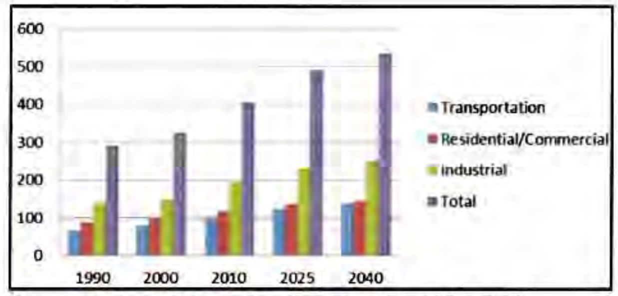

Figure 1: Projected Energy Use by Sector (Quadrillion BTU)

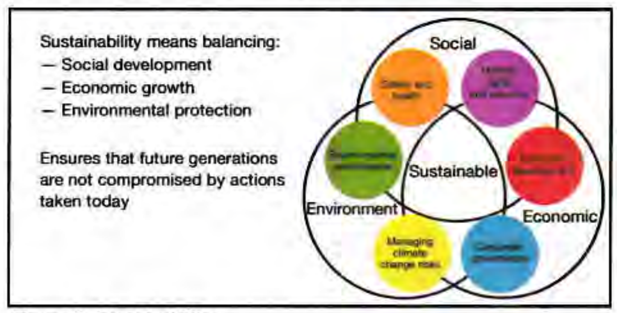

Figure 2: Sustainability

ENERGY LOSS IN INDUSTRIAL EQUIPMENT

The causes of efficiency loss in gearboxes generally fall into two categories, those which are speed dependent and those which are load dependent. The load dependent losses are of interest as they result from internal fluid friction and metal-to-metal contact. They may be improved upon by using a suitably formulated lubricant, with carefully selected base oils and additives to improve efficiency.

Frictional losses can occur under all three lubrication regimes: hydrodynamic, elasto-hydrodynamic (EHL) and most significantly boundary lubrication, where metal surfaces are in contact. See Figure 3.

Hydrodynamic lubrication exists in systems where the contact occurs over a relatively large area and the pressure in the contact region is not too high. A significant part of the energy losses in the hydrodynamic scheme are related to the viscosity of the oil under operating conditions. Components operating under this regime are found in a large number of industrial and automotive applications and most often include journal and thrust bearings.

Elastohydrodynamic lubrication is associated with components where the load is supported over a small area. In this system, the load is so high that the surface of the mating components elastically deforms to form a small contact patch. The lubricant film is drawn into this area and separates the surfaces. Under these high pressure conditions, the oil is sheared, with the extent of shear loss determined by how the oil behave under high pressure conditions, greater than 1 Gpa. Examples include all types of rolling element bearings, such as those found in engines and gears.

Boundary lubrication occurs as the bodies come into closer contact at their asperities; the heat developed by the local pressures causes a condition which is called stick-slip and some asperities break off. At the elevated temperature and pressure conditions chemically reactive constituents of the lubricant, commonly referred to as anti-wear additives and friction modifiers, form a chemical film on the surface and prevent direct metal-to-metal contact. This phenomena may occur in all

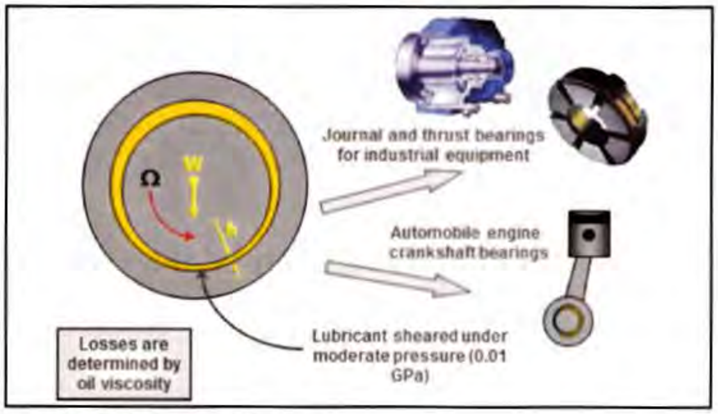

Figure 3a: Hydrodynamic Lubrication

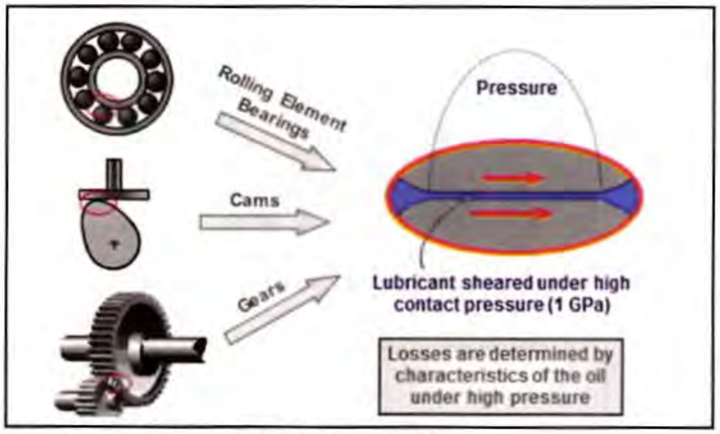

Figure 3b: Elastohydrodynamic Lubrication (EHL)

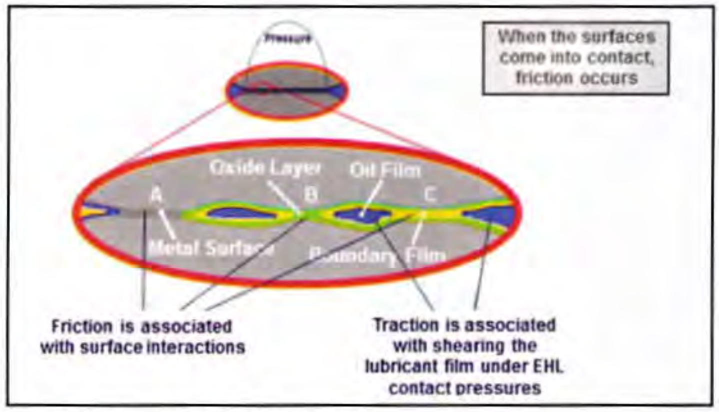

Figure 3c: Mixed and Boundary Lubrication

components found in engines and gears and is the most common of the lubrication regimes experienced [4].

LUBRICANT BENCH AND RIG TESTING

Synthetic lubricants may be used to improve energy efficiency, however not all synthetic lubricants provide the same benefits5. In controlled testing, three synthetic oils were tested and the results showed that Polyalphaolefin (PAO, API Group IV)-only based gear oil were superior with showed an average of 6% efficiency over an API Group III / PIB-based gear oil.6 Further testing found PIB-containing gear oils showed significant shear loss versus PAO-only based gear oil, with corresponding higher wear rates which would result in shorter equipment life.

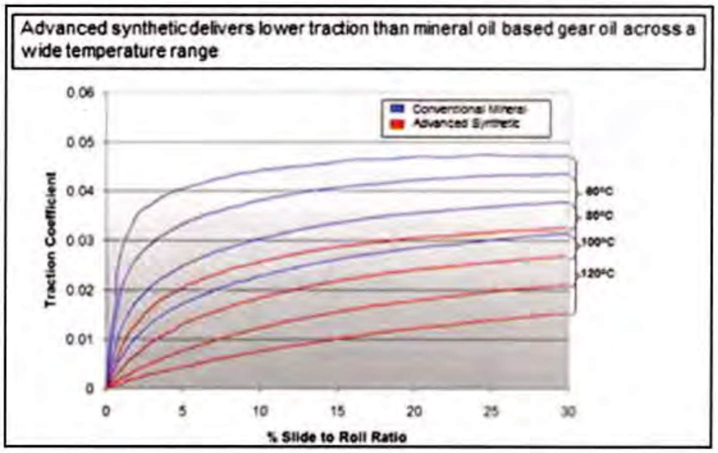

Figure 4: Low traction benefit.

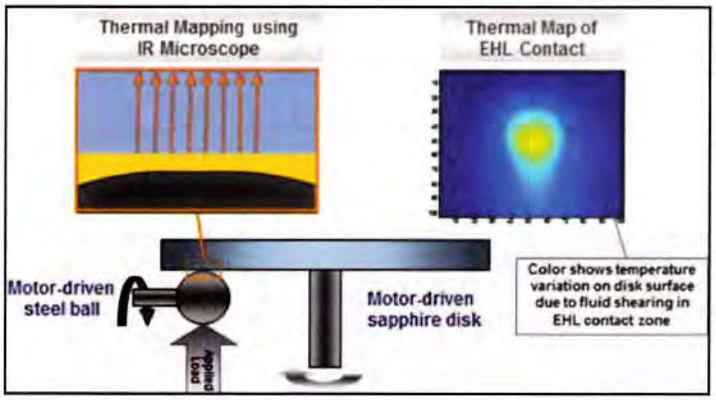

Figure 5: EHL thermal mapping.

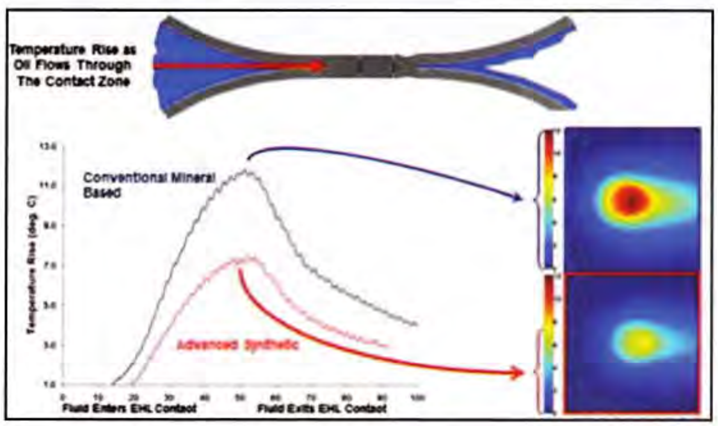

Figure 6: EHL thermal mapping results.

Experiments to measure finished lubricant-related energy efficiency benefits are inherently challenging. A Mini Traction Machine (MTM) was used to measure the traction forces transmitted across a lubricant film under varying amounts of sliding while controlling load, speed and temperature. The actual traction coefficient measurement over a range of slide to roll ratios shows that synthetics have much lower traction coefficient than typical mineral oil based products. See Figure 4. This leads to more energy efficient operation, reduced heat generated, and lower overall system operating temperatures.

Testing was also carried out using a conventional EHL ball on disc rig equipped with temperature mapping using infrared imaging.[7] This provides a map of lubricated contact under highly loaded EHL conditions with varying amounts of sliding, while controlling load, speed and inlet temperature. The data generated showed variation in temperature as the disk surface is heated due to shearing of the fluid in the contact zone (Figure 5). The temperature rise is a function of the heat generation per unit area, which is the product of the fluid shear stress under the contact conditions and sliding speed.

For a given sliding speed, fluids with lower shear stress will provide lower temperature rise across the EHL contact. Advanced synthetic lubricants were evaluated against conventional mineral oil based lubes and found to reduced the temperature in the contact zone by >4°C, leading to lower overall system operating temperatures.

The next phase of testing was done in a highly instrumented worm gear box specifically developed by ExxonMobil to evaluate lubricant efficiencies. Worm gears were chosen because the worm forms elliptical contact against the wheel, where sliding motion predominants, creating a relatively inefficient energy transfer environment (70 – 80%) compared to other types of gearing.

A Modular Small Worm Gear (MSWG) test rig was used in this part of the testing. It employs two torque meters to measure torque into and out of the gearbox. The output torque is divided by input torque to provide the percent efficiency. Torque, rather than current, is measured in this test as current/ voltage measurements have much higher associated error.

Figure 7 shows the efficiency of advanced synthetic technology (reference oil) and a mineral oil based gear oil. Efficiency is determined from data from the latter part of the test run, after the gearbox reaches thermal equilibrium. The gearbox is run at full speed (1800 rpm input), 100% of rated load at 20/1 reduction ratio. Each gear box is separately calibrated and run-in, and tests are bracketed by reference oil runs to take into account any consistent drift in the data.

The reproducibility of this test has been determined to be +0.25% (absolute). The results from this highly controlled testing indicate an energy efficiency improvement of 3% when comparing these two lubricants.

Thermo-graphic images (Figure 8), taken from the MSWG show that advanced synthetics run approximately 15°C (27°F) cooler than typical mineral oil based industrial gear oils. Lower operating temperatures lead to increased equipment life, improved efficiency and reduced maintenance costs.

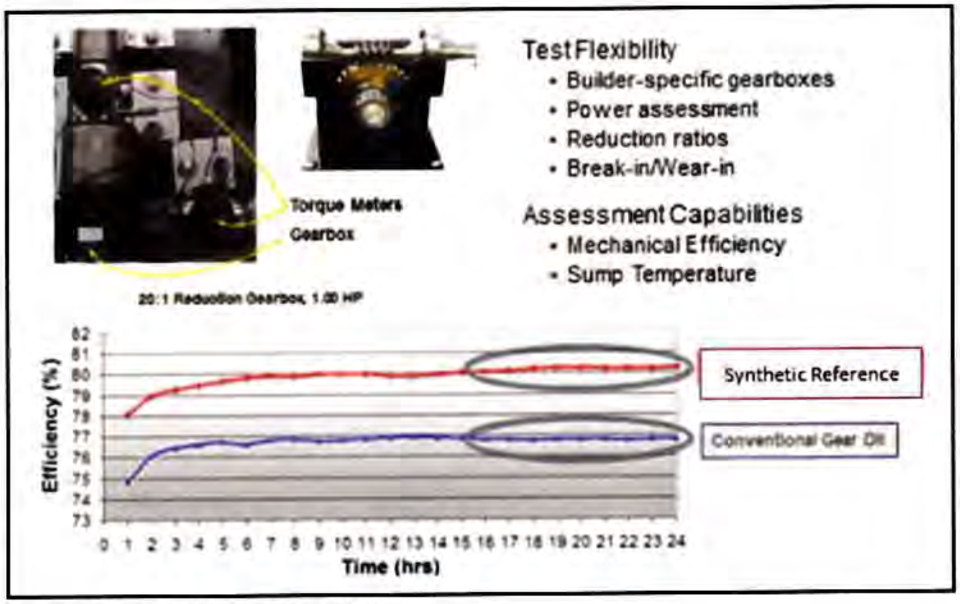

Figure 7: Modular small worm gear test rig.

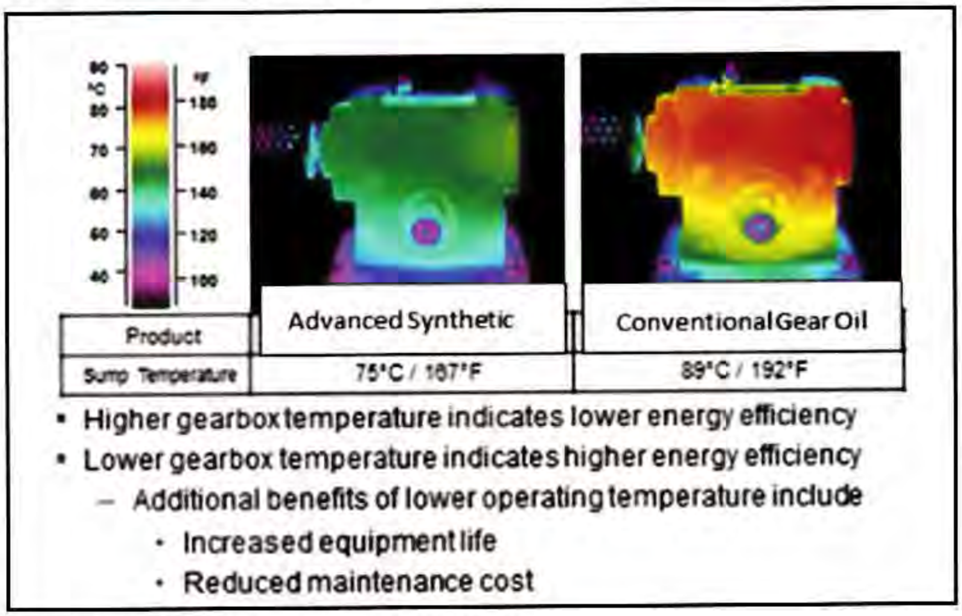

Figure 8: MSWG testing confirms energy efficiency benefit.

LUBRICANT FIELD TESTING

Field testing of advanced synthetic technology was carried out in a Falk double reduction gear box driven by an 1150 HP induction motor at a taconite mine in Minnesota. The gear box is coupled to a primary ore conveyor that is approximately one-quarter mile in length. It is supported by a series of guide rollers and standards, with the rollers positioned in a concave arrangement that cups the conveyor to channel the taconite ore to the center of the conveyor as it being transported.

The Falk gearbox is a double reduction parallel shaft speed reducer with a ratio of 39.4:1, driven by a 4160 VAC, four pole, 3-phase 1150 HP GE induction motor. The motor is directly coupled to the high speed input shaft of the gear box providing 1792 RPM that is reduced to 45 RPM at the gear box output shaft. The maximum calculated torque output from the gear box at is 137,189 ft-lbs.

The efficiency study was undertaken using an A-B-A-B comparison methodology. The conventional gear oil representing the 'A' series studies and the advanced synthetic representing

Figure 9: Primary ore conveyor and gearbox.

Figure 10: Torque readings captured by a strain gage.

the 'B' series. The premise was to determine if one gear oil type was more efficient, requiring less motor input power to generate comparable torque as a function of loss reduction in the gear box. During the study, power input to the motor was compared relative to the torque required to transfer the taconite ore over various time periods. Load curves were created for each period as function of input power to the motor versus output torque produced by the gearbox.

To obtain measurements, a Fluke 1760 three phase power analyzer was used to monitor input power to the motor. Input power was captured at the main MCC feeding the motor, where true three phase power readings were continuously recorded along with motor RPM at 200msec intervals. The power recordings were time synchronized with the torque values taken on the output shaft of the gear box. The readings were captured using a strain gage mounted to gear box output shaft. See Figure 10.

As the conveyor belt transports batches of ore, the power consumption cycles up and down. Amidst these cycles, 10 periods of steady state operation were identified. These steady state periods were the basis of the efficiency calculations, and these periods were considered as independent samples to calculate confidence intervals on the estimates of mean efficiency. Including both high and low load conditions, using 95% confidence intervals, the advanced synthetic lubricant was found to be 3.6% (+/- 1.3%) more efficient than the conventional mineral oil based product as shown below (Figure 11). [8]

Based on measured watt usage and assuming continuous operation, using the advanced synthetic lube can save from \$8,700 to \$17,400 per year using a range of \$0.05 to \$0.10 per kilowatt hour.

CONCLUSION

Based on the results presented, advanced synthetic products have the potential to significantly reduce energy consumption in gearboxes, demonstrating energy savings

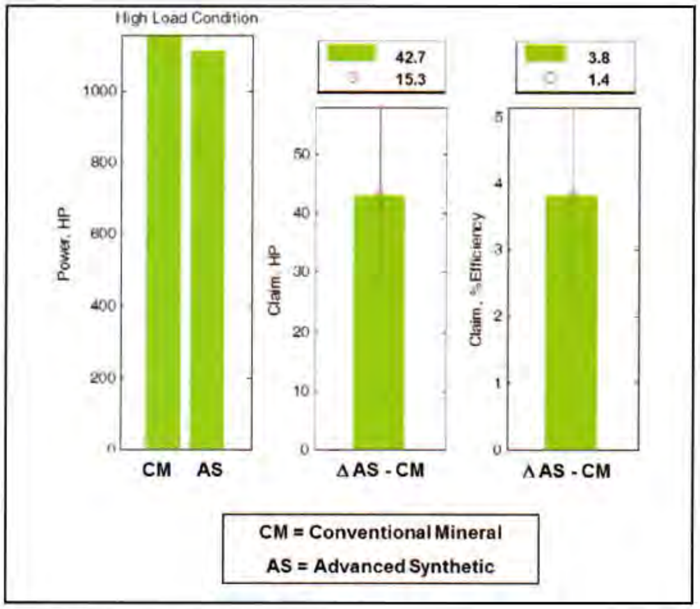

Figure 11: Energy efficiency comparison.

of up to 3.6 percent versus conventional mineral based gear oils.

Our test gear box held 330 gallons and the cost to upgrade the gear oil from mineral to advanced synthetic was approximately $6,600. Based on the test results, the increased oil expense would be recovered after 5 - 9 months of operation and any addtitonal runtime achieved on a single charge of oil, would be energy savings realized by the user.

In sustainability terms, the choice of proper advanced synthetic lubricant clearly leads to increased return on capital investment and provides economic growth. Remember, energy usage is predicted to grow substantially over the next 30 years. Using an energy efficient lubricant is one way to help meet this demand.

REFERENCES

[1] ExxonMobil: 2012 The Outlook for Energy: A View to 2040
[2] ExxonMobil: Fuels & Lubricants, http://exxonmobil.com/lubes/sustainability
[3] AGMA 925-A03
[4] Improving Energy Efficiency Through Optimized Lubricants, F. Guerzoni, Utilities Manager, February 2008.
[5] API: "API Base Oil Interchangeability Guidelines for Passenger Car Motor Oils and Diesel Engine Oils"
[6] Improved Temperature Mapping of EHL Contacts, Reddyhoff, T., et. al., Proc. I. Mech. E. part J: Journal of Engineering Tribology, 2008, pp 1165-1177
[7] Mobil Industrial Lubricants, "Mobil SHC Gear Next-Generation Gear Lubricants," http://www.mobilindustrial.com/IND/English/products_mobil-shc_mobil-shc-gear-series.aspx

ABOUT THE AUTHORS:

Kevin Harrington has over 25 years of lubrication-related experience and manages technology programs for the Mobil SHCT portfolio of flagship industrial lubricants sold under the MobilT brand. David Blain has spent most his career developing industrial lubricants, and is the holder of 24 US patents and author of several industry papers and presentations. Angela Galiano-Roth, industrial lubricant technology program leader, has worked for ExxonMobil for more than 25 years and is an inventor of 15 lubricant-technology patents. Rick Russo is product technical advisor for ExxonMobil. He has worked for ExxonMobil since 1988.