THE SOUTH AFRICAN INSTITUTE OF TRIBOLOGY SA TRIBOLOGY PROJECT 2010

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ABSTRACT

The cost and energy saving potential of tribology to South Africa has never been determined; a project to establish this cost was established through the Department of Science and Technology. Although some pockets of excellence were discovered, the major project findings were that, if considered at all, tribology is most often considered to be lubricant related, which is a commodity function relegated to the lowest level of labourer. Skill losses and management practices have resulted in a drop in maintenance standards and increase in machinery failures; root cause analyses are seldom, if ever, completed, and energy consumption is typically a production expense with no thought of energy conservation through tribology. The cost and energy saving potential of tribology to South Africa could not be established because data recording across industry is insufficient. A significant mindset change is therefore required to bring tribology out into its rightful position throughout industry; this should include sharing of best practices by establishing a centre of excellence that can also solve common industry problems, and establishing a Research and Development University Chair would promote tribology and could be used to conduct research that is specific to South African conditions.

1. INTRODUCTION

The objective of this study was to determine the cost and energy saving potential of tribology to South Africa. The initial methodology was to conduct 80% of the data collection through industry questionnaires based on previous such projects completed internationally. Unfortunately there was no international questionnaire available. A questionnaire was therefore developed[1] and circulated to approximately 4,000 potential respondents. The response was insufficient and hence face-to-face site visits were necessary to gather the required information. Most of the sites visited did not have or would not share the information required for this project because the cost of energy consumption due to friction and failures due to abnormal wear are typically not monitored. This was a concerning finding of the project.

2. TRIBOLOGY

After gravity, tribology is the second most important property of matter; it is a complex science that impacts every person in almost every situation, and has a tremendous effect on industry at large, from energy consumption and wear in the largest machines to the joints in our bodies. Tribology is the study of friction and wear. Without friction the world as we know it would not exist: we would all slide around endlessly. On the other hand friction can only occur when two bodies are in relative rubbing motion, and rubbing means that the bodies are in actual contact. Friction generates wear and heat. Heat developed through friction wastes energy, and sometimes requires more energy to dissipate the heat, such as through a cooling system. At the same time wear takes place on both rubbing surfaces.

Although friction has been used for many years, probably since our primate predecessors started sharpening sticks; it is only more recently that it has been studied as a discrete science that includes wear and energy usage.

During the mid 1960's Professor Peter H Jost was requested to consider the position of lubrication education and research in the UK. From this humble start Professor Jost realised that lubrication, or rather, correct

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[1] The purpose of the questions was to develop an understanding of the level of knowledge and training in tribology, tribology costs in relation to maintenance and turnover, cost of down time, percentage of downtime related to tribology, typical; failures, condition monitoring, maintenance philosophy.

lubrication, was only a small part of the bigger picture, and that friction and wear encompassed both lubrication and the properties and nature of the surfaces that were rubbing together. With the help of the Oxford English dictionary he called this old, but recently defined science: tribology.

Jost's final report, now commonly called the Jost report, showed that in 1965 terms the UK was losing a conservative £500 million per annum through poor understanding of tribology, and the associated losses in energy and wasted machinery component life.

3. OVERALL PROJECT GOAL AND OBJECTIVES

The objective of this study was to determine the cost and energy saving potential of tribology to South Africa. Since tribology is about the understanding and control of friction, and friction consumes energy and generates wear, this objective was seen as to determine the extra cost of energy lost due to friction, and, since wear consumes machinery, the cost of wear that could otherwise be reduced or eliminated.

Because tribology is universal it covers all of industry, both government and private sector, and all forms of mechanisation. The objectives of this study were to establish both the costs and potential savings by industry type and by application, considering the following cost areas:

- Energy, consumption and savings potential
- Environment
- Maintenance
- Replacement costs
- Breakdowns
- Potential to increase component life
- Potential to increase equipment and machinery utilisation from greater mechanical efficiency

The outcome of the study could then be used to benchmark the country and highlight areas of concern where greater effort is required, for example in certain industries or applications, in general education, specific education, or research and development.

4. METHODOLOGY

The planned steps to complete this study were:

4.1 Literature survey

An international literature survey was conducted to establish baseline information on maintenance practices and potential areas of savings through tribology.

4.2 International contact

International contacts were used to expand the baseline information for this project. Both through international contact and literature surveys a suitable online questionnaire was developed to survey industry in South Africa covering the agriculture, construction, heavy manufacturing, light manufacturing, metals beneficiation, open cast mining, paper & pulp, petrochemical, public service, power generation, quarry, transport, underground mining and utilities.

Through this project South Africa has become a foundation member of an international tribology project calledTribology Global Survey. The other members of this group are the USA, Finland, Italy, Switzerland and Austriaproject, including Italy, USA, South A The objectives of this project are:

- To complete a global survey on how much energy is consumed by industry to overcome friction and to replace worn out parts and components.

- To show how much energy can be saved by developing and implementing new scientific achievements and new technical solutions to reduce and control friction and wear.

4.3 Online survey

An online survey questionnaire was issued to all members of the SAIT and the South African Institute of Mechanical Engineers. It was expected that 80% of the information required for the project would be acquired through this survey. Unfortunately there was a poor response of around 1 percent to the survey.

4.4 Site visits

Individual site visits were arranged with key players in different industry sectors. By visiting the different sites, a "dipstick" check of the state of play in industry was obtained. Due to the timeframe and magnitude of the project, only industries that used relatively high volumes of lubricants were focused upon. This information was complemented with industry expert information as well as Original Equipment Manufacturers (OEM's) analysis and knowledge of the market. Due to the competitive nature of the industry the details of the sites visited and individual information discussed remains confidential and only generic issue have been used in this report.

5. PROJECT FINDINGS

Tribology should be recognised and supported across industry from the boardroom to the shop floor, but this study has found that, if considered at all, it is most often considered to be lubricant related, which is a commodity function relegated to the procurement department and the lowest level of labourer.

As manufactured, most equipment operates at peak efficiently, and efficiency declines with service as wear becomes a factor. At the same time optimal contact between surfaces is lost and friction becomes a factor, resulting in increased energy consumption; and eventual equipment failure.

A major cause of equipment wear is solid particles or dirt in the lubricant. Most equipment systems are fitted with filters to control dirt, however these filters need to be managed and maintained. Proactive condition monitoring assesses and records machine, lubricant and filter condition to ensure continuous optimised operation.

Well maintained machines that are correctly lubricated and monitored by proactive maintenance will both minimise equipment failures, and maintain optimal energy efficiency over the life of the equipment.

High level findings of the project were:

- There is little understanding of tribology across industry, where tribology is mostly interpreted as lubrication, and lubrication makes up 0.24% of annual turnover, therefore the cost of lubrication is lost in the greater scheme of things. Further, since lubricants are considered to be commodity items and are a cost item, the lowest cost or most expedient suppliers are chosen; this is often regardless of quality or performance issues.

- Management is generally short term profit driven, and maintenance is considered expendable or is more often sacrificed to production.

- Incorrect performance measures inhibit management from seeing the long term opportunities of improving machine efficiency and operability through correct maintenance and lubrication

- Typical lubricant consumption of most operations in South Africa is in the region of 20% of the installed lubricant capacity per annum, while the international benchmark is approximately 10% of installed capacity.

- That average drain periods are approximately equal to international standards. When considering that lubricant consumption in South Africa is approximately double the international benchmark, this indicates that equipment failure rates are significantly higher in South Africa.
- Average bearing life has dropped by two thirds and gearbox lifetime to overhaul by 80 to 90% over the past 20 years, this trend is ascribed to a lack of skills, resulting in poor alignment during assembly, and excessive dirt entry throughout the supply chain.
- There is general industry comfort with historic failure trends and costs, rather than understanding the root cause or causes.
- Overall, if industry was able to get back to basics and focus on tribology, energy costs could be reduced by between 8 and 20%, and maintenance costs by 30 to 50%.
- It is of critical importance that industry establishes overall maintenance targets that will result in reduced lubricant consumption, since this will address friction and wear in its greatest detail

5.1 Transport

As of March 2010 approximately 8.7 million petrol and diesel powered vehicles were registered to operate on the roads of South Africa[i].This vehicle parc consumes approximately a quarter of South Africa's annual energy demand.

The bulk of the vehicle parc are passenger vehicles, most of which are spark ignition (petrol) engines. The average vehicle age is considered to be relatively old and the parc is made up of a mixture of Japanese, European and American manufacturing technologies. This mixture of manufacturing technologies impacts the lubrication technology that is required in South Africa for these vehicles to operate correctly.

Fuel demand in South Africa is approximately 20 billion litres (www.dme.gov.za), but lubricant demand is not readily available. However based on historical data (2006) it is understood that in excess of 60% of the passenger car engine oils sold in South Africa are of low quality, and a large volume of monograde lubricants are currently being sold. Research has shown that changing from monograde to multigrade engine oils can result in fuel savings of between 2 to 5%, as indicated in Table 1.

Reference Oil	Tested Oil	Test Description	% Improvement
SAE 40	**10W-40**	**Mono to multigrade**	**2.0**
15W-40 **(102cSt)**	**10W-40** **(85cSt)**	**Decrease Viscosity** **Increase Viscosity Index**	**1.9**
10W-40	**5W-30**	**Viscosity down**	**1.5**
SAE 40	**5W-30**	**Overall result**	**5.4**

Table 1 - Fuel savings that can potentially be achieved by changing from the Reference oil to the Tested oil.[ii]

Replacement of theseobsolete low quality monograde oils with appropriate quality oils would reduce engine petrol consumption by about 4%, resulting in an estimated saving of 15 million litres of petrol per annum. At the same time use of appropriate quality modern lubricants will increase average engine life and reduce maintenance costs, provided the correct services and service intervals are applied.

Further national reductions in fuel consumption can be achieved by use of friction modifiers that are introduced into the engine via the fuel. These fuel borne fuel economy additives have the potential to improve fuel economy by between 1 and 4% across all engine types. A reduction of only 1% would reduce South Africa's annual fuel consumption by 200 million litres.

5.2 Bearings

Bearings are required wherever there is permanent relative contact between two surfaces, no matter how lightly loaded the surfaces are; the purpose of the bearings being to reduce friction and wear, and to reduce repair costs when the component is refurbished. Two major bearing types exist; sliding contact, or in industry, plain bearings, and rolling contact. All bearings, regardless of type must be correctly aligned to ensure even loading, and must be correctly lubricated to ensure optimum life. The presence of any solid particles, whether introduced or internally generated, will cause abrasion, resulting in abnormal wear and potential failure. Bearing selection is typically dependant on the application, loads and speeds.

The bearing market is relatively large in South Africa, and some locally produced bearings are exported internationally. The bearing market and cost of failures due to abrasive wear and misalignment are shown in Table 2.

	Plain	Rolling Element
Industry Size	R 110 million Approx. 25% is exported	R 3,800 million
Cost of failures due to dirt ingress	R 50 million	R 2,280 million
Cost of failures due to misalignment	R 29 million	R 1,213 million

Table 2 – Bearing industry size

Bearings and gearboxes are the cornerstones of all industrial equipment. Over the past 20 years bearing life has decreased by about two thirds. The major causes of bearing failures are dirt contaminationof lubricants through the entire supply chain (60%), and misalignment of components when installing (35%). The major factors affecting this situation are:

- A general lack of artisan skills:
    - Why align
    - Lack of tools
    - Production pressures over doing the job correctly
    - Dirt does not lubricate
- Knowledge of lubrication is limited and often hearsay, sales talk or previous experience is used, which may be an improvement in the process, but not necessarily the best option for a specific plant or application. There is seldom sufficient knowledge to understand the true facts of the situation
- Root cause analyses are rarely conducted and hence the true or real problems are not identified or addressed

5.2.1 Energy losses

The power loss in a plain bearing is dependent on the film thickness and hence the viscosity of the fluid that is used, assuming that the fluid is in laminar flow. As a result the viscosity choice is essential in minimising losses in the bearing. Most electric motors operate at about 1,500 rpm, and should be using an ISO 32 grade oil, but often due to rationalization an ISO 68 grade is used instead - this can result in a power loss exceeding 20%.

A possible solution to this is the use of magnetic bearings, where power loss is approximately 10% of that in a perfectly lubricated bearing. This type of technology can be retrofitted to current installations. An example would be a typical large boiler feed pump, where 70kW can be lost in the 2 plain bearings. By using magnetic bearings these losses would be reduced to about 7kW, and the payback period would be approximately 18 months.

Magnetic bearing life is essentially exponential, with the only wear being to the slave bearings, should there be a loss of power. The increased cost of magnetic bearings is really in the computers and software that is required to keep the shaft centred at operating speeds. Work is currently being conducted to use this technology in vehicle bearings.

Actual energy losses in the bearings of a major new power station being built in South Africa were calculated by a local bearing manufacturer and are summarised in Table 3; these losses assume that the correct lubricant is applied in every bearing.

It was estimated that 10.4 MW would be lost in the power station bearings with the correct oil grade, while use of an oil with one ISO viscosity grade higher would result in 13.5 MW being lost. Energy consumption could be reduced to 1 MW should magnetic bearings be introduced. The savings that could be realised, should magnetic bearings be used, would be in the order of 24 million rand per annum, at the current electricity price. This would also reduce overall maintenance costs and have an impact on the manpower required for maintenance.

	Number of Bearings	Energy Losses Correct grade	Energy Losses one ISO grade higher	Energy Losses Magnetic Bearings	Energy Losses Rolling element bearings
Plain Bearings	Approximately 550	10.4 MW	12 MW	1 MW	
Annual cost[2]		R 26,280,000	R 30,485,000	R 2,628,000	

Table 3 - Energy losses in a typical coal fired power station

The operating temperature of a bearing is an indication of the wasted energy that is being converted into heat due to elastic deformation, internal lubricant shear, bearing wear or misalignment. The temperatures of both bearings on a specific shaftshould be the same, a quick sample of bearing temperatures across industry indicated that there was considerable variation, as is indicated in Table 4:

Unit	Bearing 1 Temperature	Bearing 2 Temperature	Comment
Large Gearbox	35°C	36°C	Good
Pump 1	33°C	48°C	15 – 20% energy loss
Pump 2	32°C	45°C	15 – 20% energy loss
High pressure compressor	51°C	44°C	~10% energy loss
Blower fan	48°C	79°C	Manual greasing – dirty nipples
Pump 2	32°C	45°C	15 – 20% energy loss
Pump 1	33°C	48°C	15 – 20% energy loss

Table 4 - Measured bearing temperatures

[2] Based on 8,760 hours per annum and R 0.30 / kWh

5.2.2 Conveyer idlers

Conveyers are an effective and efficient method of handling materials, and hence are used extensively in mining and industry. Rollers or idlers are used to support the belt as the load is transported. These idlers operate on sealed rolling element bearings and absorb energy, which is transferred into heat. A small section of conveyers was examined in an attempt to determine the actual efficiencies of the systems. This project revealed the following:

- The energy efficiency of most conveyor systems is not monitored or measured. One company is however currently conducting an energy efficiency study on a conveyer belt to determine the effectiveness of different intervention strategies.

- The frequency of roller replacements is typically high, one example is that more than 20% of the rollers in a network of 500 km are replaced annually. The international benchmark is less than 5%. It should be noted that this replacement rate is not the same across all industries.

- Roller condition will affect the energy required to drive the conveyor, and heat in a roller represents abnormal friction. An infra red (IR) camera was used to quickly identify rollers that needed replacement before the bearing had failed. The bearing in Figure 1 indicated a hot bearing that was about to fail; increased friction (energy wastage) is being turned into heat. The other bearings were operating at approximately 18 °C.

- Some idlers were seized or broken, increasing the idler and belt temperature, and wasting energy.

Active management of the idler (selection, grease selection) and replacement will ensure that system efficiency is improved and maintained.

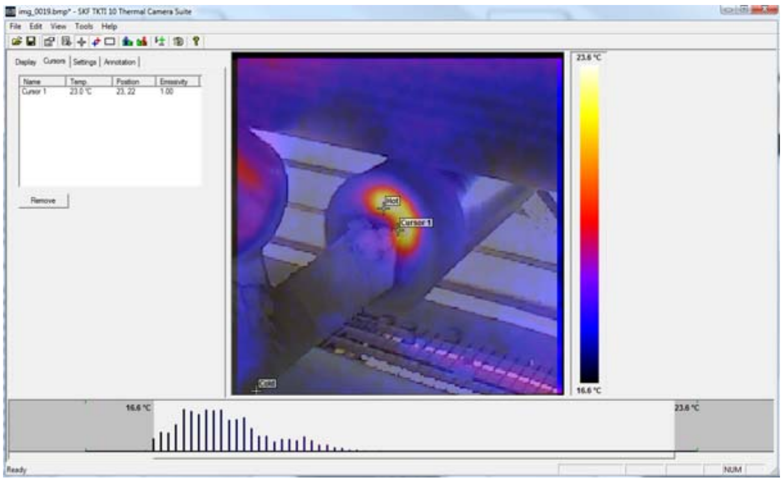

Figure 1 - Roller idler bearing showing elevated temperature

5.2.3 Lubricant cleanliness

Improving average lubricant cleanliness increases component life considerably, thereby reducing maintenance costs; this is due to the extremely high loads and small clearances that occur under actual operating conditions. Life extension factors relative to lubricant cleanliness, as measured by ISO 4406, are indicated in Table 5.

Current MachineCleanliness, (ISO4406)	Target 1	Target 2	Target 3	Target 4
28/26/23	25/22/19	22/20/17	20/18/15	19/17/14
27/25/22	23/21/18	21/19/16	19/17/14	18/14/13
26/24/21	22/20/17	20/18/15	19/17/14	18/16/13
25/23/20	21/19/16	19/17/14	17/15/12	16/14/11
25/22/19	20/18/15	18/16/13	16/14/11	15/13/10
23/21/18	19/17/14	17/15/12	15/13/10	14/12/9
22/20/17	18/16/13	16/14/11	15/13/10	13/11/8
21/19/16	17/15/12	15/13/10	13/11/8	-
20/18/15	16/14/11	14/12/9	-	-
19/17/14	15/13/10	-	-	-
18/16/13	14/12/9	-	-	-
17/15/12	13/11/8	-	-	-
16/14/11	13/11/8	-	-	-
15/13/10	13/11/8	-	-	-
14/12/9	13/11/8	-	-	-
Life Extension Factor	2 x	3 x	4 x	5 x

Table 5 - Roller contact bearings: required new machine cleanliness

5.3 Gears

Over the past 20 years gearbox life has decreased by about four fifths[iii]. As with bearings, the major causes of gearbox failures are dirt contamination of lubricants through the entire supply chain, and misalignment of components when installing. The major factors affecting this situation are the same as with bearings, and root cause analyses are rarely conducted. A typical shaft failure due to misalignment is shown in Figure 2.

Figure 2 – Typical shaft failure due to misalignment, shaft service was 6 months.

5.3.1 Energy losses

The efficiency of a gear box is dependent on a number of factors, including :

- Type, as indicated in Table 6
- Type of lubrication system
- Lubricant type – viscosity, mineral or synthetic

	Efficiency per stage
Worm	80
Helical	97 – 98
Spur	97 – 98
Hypoid	95
Bevel	97 – 98

Table 6 - Gearbox efficiency by type

Some gear oils are more energy efficient than others due to their lower coefficient of friction. Synthetic oils are generally more energy efficient than mineral oils because they are inherently more slippery; they also have better oxidation and thermal stability, which means the gear oil lasts much longer.

The biggest increases in gearbox efficiency can be realised in gear types that normally have lower efficiencies, such as worm drives. Tests conducted by certain lubricant manufactures have indicated that worm boxes operating at approximately 60 percent efficiency with a mineral oil, increase to 70 percent with polyalphaolefin (PAO) and 78 percent with polyglycol(PAG) types of synthetic lubricants.

The energy saving that can be made with one or two gearboxes may not be significant, but in one plant consulted where approximately 100 worm boxes were operating on mineral oil in a section of the plant (conveyor belts) the energy savings potential is significant.

By choosing high-quality synthetic gear lubricants, end users will both save energy and reduce operating costs through reduced maintenance, longer oil change intervals and less wear, however it was found that most users did not want to pay more for the synthetic lubricants and therefore remained on mineral products.

	Mineral oil	Synthetic oil
Ambient temperature	28 °C	
Bulk oil temperature	63°C	59°C
Amp-hours	338 Ah	306 Ah
Kilowatt-hours	89.6kWh	79.8 kWh

Table 7 - Comparative performance of synthetic and mineral gear lubricants

In a specific field trial conducted by a prominent oil company in South Africa to determine the energy saving potential of synthetic oils over mineral oils, the energy reduction resulted in an annual saving of R 31,000 for the trial gearbox, and a payback of the lubricant in under 4 months, this despite the fact that the synthetic oil cost was approximately 8 times more than that of the mineral lubricant.

The trial results are shown in Table 7.

5.4 Metalworking

Metalworking is used in all industries to manufacture or remanufacture parts by machining metal from the component surface. During this process the metal surface is not cut, but is removed through a process of deformation; this process therefore requires considerable energy to deform the metal, and the energy is eventually released as heat. Coolants have therefore been developed that include a lubricant, which are circulated from a sump that will both carry away the heat formed during metalworking, and lubricate the process. The major benefits of a coolant are:

- Reduced tool wear
- Improved tool life
- Improved finish of machined parts
- Reduced energy consumption due to reduced friction

Because water has a high specific heat it is an ideal coolant, and traditional metalworking coolants have been oil or synthetic emulsions that contain many other chemicals to stabilize the emulsion, prevent bacterial growth in the coolant, and rusting or corrosion of the tools and machines used in the process. Bacterial growth in emulsions is a natural process, where the bacteria consume some of the components of the emulsion, breaking down the coolant, and produce highly acidic by products that accelerate corrosion, and are harmful to operator's health. Metalworking coolants are difficult and expensive to dispose of, generally being more expensive than the initial cost of the coolant.

5.4.1 Minimum Quantity Lubrication - MQL

An alternative method to cooling and lubrication in the metalworking process is to machine with a 'minimum quantity lubricant', or MQL. During the early 1990s a South African company pioneered MQL technology. MQL requires special micro pumps that can deliver between 3 and 30 micro litres per pulse. By adding pumps and changing the pulse rate, the dosing parameters can be established to meet the specific needs of an operation. Dosing is accompanied by carefully controlled air to disperse the lubricant at the exact point of lubrication, to blow away chips formed from the metalworking process, and to provide cooling of the tool. At present this technology is limited to the machining of non ferrous metals.

The major benefits of MQL are:

- Significant reduction of coolant volume, reductions of 60 000:1 have been reported internationally (Vogel)
- Elimination of the coolant circulation system
- Eliminates disposal of spent coolant
- Cleaner operating conditions
- Improved operator health
- Improved surface finish
- Improved tool life
- Lower energy usage
- Environmentally acceptable
- Every drop of MQL lubricant is fresh, unlike in conventional lubrication, where the neat or water soluble cutting fluid is degraded as it is constantly circulated

5.4.1.1 MQL Case Study

While MQL has not been developed for all applications, the following case study shows the results achieved through MQL in a specific application that involved sawing aluminium.

- For the same tonnage of metal throughput the coolant volume reduced from 65 100 litres to 110 litres; the previous water soluble oil coolant reticulation system was decommissioned.
- Metal chips produced by the cutting process are re-melted for re-use, but chips coated in water soluble oil coolant can cause a furnace explosion. When using MQL the chips go directly into the melting furnace, making the chip washing, centrifuging and drying oven redundant.
- On the production floor, housekeeping and safety (operator slip/sliding) improved and the problem of skin disorders disappeared.

- Ingress of unwanted moisture into gear boxes, bearings, slides, electronic controls etc. disappeared, resulting in less maintenance and downtime on main equipment.

- Saw blade changes dropped from 69 to 18 per annum i.e. a ratio of 4:1, and blade repair costs decreased 11 fold as the blades were re-sharpened in place of renewal.

The total annual savings of R 424 097 are summarized in Table 8.

	Lubricant volume	Lubricant cost (R)	Average blade changes per year	Blade repair cost per year (R)	Cost to remove used lubricant (R)
Previous coolant	65 100	314 160	69	104 000	19 600
MQL	110	4 400	18	9 263[3]	0
Annual savings		309 760		94 737	19 600

Table 8 - MQL case study - cost savings

In metalworking, energy consumption is a good indicator of the efficiency of the operation; the moment the tool goes blunt, the machine starts drawing more power and the noise level and pitch increases. Energy consumption was however not monitored in this case study.

5.5 Hydraulics

Hydraulic power is used extensively for transferring useful power in numerous applications; however overall system efficiency is not very well understood. System efficiency losses can be significant, especially when operating at high pressures and can be affected by the design of the system. The South African market is worth R1.5 billion per annum, split approximately into 70% replacement parts and 30% new installations.

Depending on the design and operation of the system, the following aspects must be taken into account:

- Viscosity of the lubricating oil at operating temperature

- The cleanliness of the lubricating oil

- Fluid residence time in the hydraulic tank

Studies have shown that over 70% of hydraulic component replacements are a result of surface degradation.

Surface degradation includes mechanical wear from abrasion, corrosion, fatigue and adhesion. Component failures lead to downtime, loss of production, component repair, fluid replacement and disposal costs. Filtration is a solution to preventing the consequences of surface degradation.

The role of a fluid filter is to control the abrasive contaminants within the fluid. With the high demand placed on modern hydraulic fluids, due to higher operating pressures and tighter tolerances, filtrations play a vital role in extending equipment life.

If a filter blocks up quickly, it is actually working well and doing its job! In this scenario there are two solutions; one is to keep changing filters until they start lasting longer as the dirt is extracted from the system, and the second is to increase the filtration capacity to cope with the volume of contaminant.

New fluids from containers are expected to be clean and fit for use, but unfortunately reality is that most new fluids have high contaminant levels and are harmful to equipment if not filtered before usage. This should be born in mind when considering fluid storage and handling.

[3] Blades sharpened instead of replacing

Many filters or filter housings have built in bypass valves, which allow fluid to bypass should the filter medium become clogged, thus preventing rupture of the medium. The bypass valves open at a predetermined differential pressure across the filter medium. If a bypass indicator system is not installed, the fact that fluid is flowing downstream of a filter does not imply that the filter is not blocked; the filter could very well be running in bypass and may require replacement. Similarly, it cannot be assumed that a bypass valve capacity is sufficient for the full fluid flow requirements of a system; as the filter becomes more and more clogged, the system may be starved of fluid as the bypass reaches flow capacity.

5.5.1 Hydraulic system cleanliness

Fluid cleanliness is often overlooked, but is critical to ensure effective operation; it is believed that approximately 60 -70 percent of all hydraulic failures are as a result of dirt contamination.

Fluid filtration of a new hydraulic injection machine recently installed in South Africa at a cost of some R70 Million was inadequate because the operator could not afford to spend R 60,000 in ensuring that the fluid was kept clean by installing adequate filtration.

Analysis by ISO 4406 conducted by a condition monitoring company recorded the cleanliness levels shown in Table 9; cleanliness levels have deteriorated over the past number of years. Approximately 100 000 used oil samples were used in this data set and analysed in a number of different ways; what stood out was that an ISO cleanliness rating of 21/19/14 seems to be about the norm for oil cleanliness in service, no matter how the data is analysed. It may be considered that compressors would be slightly cleaner than hydraulic systems, and that automotive transmission samples would be the dirtiest of the three categories, but all were similar. Similarly, new gear and engine oils have similar cleanliness levels, but hydraulic fluids appear to be a little cleaner, which is encouraging.

Year	Highest	Lowest	Average	Standard Deviation	Sample population
2010	28/27/25	15/13/10	21/19/15	02/02/02	3,152
2009	28/27/25	15/14/12	21/18/14	02/02/02	5,614
2008	26/25/23	15/12/09	20/18/14	02/02/02	5,059

Table 9 - Hydraulic fluid cleanliness rating

This data indicates that both mobile and stationery equipment is being damaged by poor lubricant cleanliness levels, which increases both the total cost of equipment ownership and machine availability.

Further, this data indicates that oil cleanliness is not part of our maintenance culture. There has however been some success where particle counts have come down when customers have an active program of setting targets, achieving them and calculating savings in monetary terms. Unfortunately these successes are few and far between.

Case studies have indicated that by installing micro filtration on hydraulic systems the life of the lubricant is extended by 4-5 times due to lower oxidation rates,which increase in the presence of dirt and water, and equipment life is also extended. By installing micro filtration systems the system cleanliness can be improved from ISO 22/19/12 to ISO 14/12/09 in a matter of days. Figure 3 shows the visual impact of ISO 22/19/12 and ISO 14/12/09 fluid cleanliness.

Figure 3 - Filter patch showing different cleanliness levels

High pressure filters are relatively expensive at approximately R 5,000 and hence are often not installed, as they are considered to be too expensive for the capital budget, however a R 40,000 expenditure on the maintenance budget is considered to be reasonable when the machine fails. Most system designers believe that a return line filter is sufficient to keep the fluid clean. Servo valves have a clearance of about 5 µm or less, and are thus greatly prone to damage and failure from particles in the fluid; systems with servo valves should be fitted with appropriate pressure line filters. In a recent example, a commonly used hydraulic pump was failing every 3-4 months with only a return line filter, and by adding a pressure line filter the pump life was extended to 7 years.

5.5.2 Energy efficiency

The efficiency of a typical hydraulic system is in the region of 40%. Control efficiencies, pipeline drag and fluid type are the major sources of hydraulic system inefficiency; however these aspects are often not taken into account when designing a system. This project has shown that some hydraulic system design experts mistakenly believe that the viscosity of the fluid does not have an impact on system performance, and that the only difference is that a "thick" oil is needed in hot temperatures and a "thin" oil in colder climates. This is however not the case as the fluid viscosity at operating temperature has a significant impact on pump performance, as is indicated in Figure , where a Vickers pump efficiency is plotted against the operating temperature.[iv]

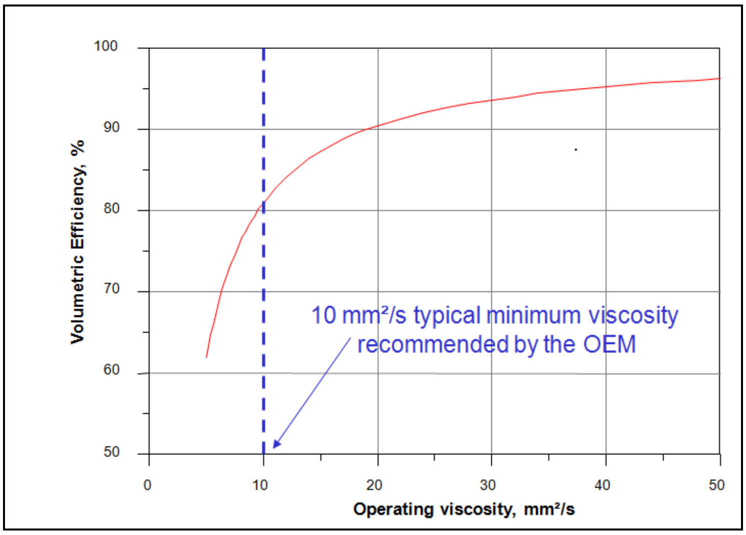

Figure 4 - Modelled vane pump volumetric efficiency @ 138 bars

This project has shown that there are a number of injection moulding machines operating in the warmer parts of South Africa that are unable to work on hot days due to excessive internal fluid leakage; when the temperature reaches a critical point the fluid viscosity reduces to such an extent that production ceases. This is normally because they are utilising an ISO 32 fluid and moving to an ISO 68 would solve the problem, increasing production and productivity. Large coolers are generally utilised to control operating temperature, but, under hot ambient conditions, coolers can become less efficient, while at the same time consuming energy.

Another widespread problem highlighted by this project is that large volumes of fluid are lost on mobile equipment due to flexible hose breakages. By implementing quality control on new hoses, predominantly by fitting only multi strand hoses, and replacing the hoses after fouryears of operation, both hose and fluid consumption can be reduced substantially. In one operation surveyed during the course of this project savings in excess of 80,000 litres of fluid per month were achieved by implementing this practice, equating to approximately R14 million per annum for the fluid alone. Due to the cost of new hoses, maintenance managers often do not want to replace hoses when they see a defect, but this should be weighed up against the cost of the fluid and associated downtime, should a burst occur.

From an energy usage perspective the pump and piping should be appropriately sized for the operation. Installing an oversized pump that uses a relief valve to dump fluid back to the reservoir only increases the heat loading in the system, with a significant wastage of energy.

5.5.3 Maximum Efficiency Hydraulic (MEHF) Fluids[v]

Viscosity is an important criterion in the selection of a hydraulic fluid. At low temperature, excessive viscosity may result in poor mechanical efficiency, difficulty in starting, and wear. As oil temperature increases, viscosity decreases, resulting in lower volumetric efficiency, overheating and wear. Pump and motor manufacturers often provide the following hydraulic fluid recommendations in their documentation:

- the maximum start-up viscosity under load
- the range of optimum operating viscosity
- the maximum and minimum operating viscosity

Selection of the optimum fluid viscosity grade will provide the most efficient pump performance at standard operating temperatures, therefore minimising lost time and energy and fuel costs for the operator.

Recent work has resulted in the development of a new performance standard for hydraulic fluids, described as Maximum Efficiency Hydraulic Fluid (MEHF). MEHF fluids.The fluids are formulated to provide a combination of high viscosity index and good shear stability, which enables all types of hydraulic pumps to deliver increased power at a lower level of energy consumption.

In field trials MEHF fluids have been shown to improve energy consumption per work cycle by up to 26%.

5.6 Wear components

Throughout industry, equipment is used in a work process where it comes in direct contact with, and becomes part of the process. Examples of this vary greatly from ground engaging, or digging tools, ore chutes, and process machines, particularly where materials are ground up, through to water pumps. At another level, all vehicles have tyres and braking systems, where tribology is critical to ensure that the vehicle is controlled at all times.

Irrespective of the area of application, wear components are developed to counter the conditions of service, controlling or minimising friction, minimising wear of the component, while maximising production efficiency.

5.6.1 Wear

Wear is the undesirable removal of material by contact with another material, and takes place in many ways. Wear materials are developed to reduce or control wear in different circumstances.

While many examples of increased component life were noted, particularly in fans and ore or rock chutes, this is a field where advances in technology are often overlooked because new technologies are not immediately embraced, and annual operating budgets allow for regular component replacement, thus encouraging complacency.

5.6.1.1 Railway track wear

It is accepted that the fatigue life of standard 280 to 290 HB hardness rail on South African railway tangent track is about 800 MGT (Million Gross Tons). This figure is also accepted for curves with a radius larger than 800 metres.However, the wear life on curves between 300 and 800 m radius is accepted to be only around 350 MGT under local conditions, due to side wear. The wear life of curves of less than 300 m radius is accepted, also due to severe side wear, to be only 150 MGT. Without rail lubrication, the rail life would be between 13 and 27 MGT. This figure is substantiated by actual experience during the early days of the Richards Bay Coal Line, around 1977.

The effect of lubrication can be improved by well managed maintenance of the lubrication equipment and process. It is estimated that good management of the lubrication process could increase the expected wear life of rails on sharp curves below 300 m radius from 150 to 200 MGT (30%) and rails on 300 to 800 m radius (medium) curves from 350 to 400 MGT (14,3%). A system similar to Transnet is calculated to be able to thereby annually save 22 000metres of rail on sharp curves and 34 000metres of rail on medium curves, a total of 56 000 metres of rail by this moderate increase in wear life. At a cost of R15 000 / ton and an additional R110 / m installation cost, this saving comes to R56,6 million / annum.

In-service experience and measurements on Transnet track suggest that the wear induced in one month of poor or no lubrication on sharp curves (radius less than 300 m) is equal to the wear produced during sixty months (five years) of good lubrication. For medium radius curves between 300 and 800 m radius, the figure gradually reduces to 30 times as the radii of the curves decrease.

Wear rates were determined in controlled track tests in 1986 to be 0,127 – 0,178 mm/MGT under dry, un-lubricated conditions and to be 0,0016 mm/MGT under very well lubricated conditions. This is a 78x (7800%) improvement.

The influence of lubrication on the wear of wheel flanges was reported to be between 17 and 22 times (1 700 to 2 200%) the "dry" wear life, depending on the type of steel used on the wheels. Increased levels of efficiency of rail lubrication caused Transnet (Spoornet) to report a six times increase in wear life of locomotive wheels after relatively low levels of lubrication on the Richards Bay Coal Line resulted in wheel re-profiling after as little as 35000 km. Poor lubrication also leads to the number of cuts on a wheel being reduced, drastically shortening its maintenance and wear life, due to the wear resulting in thin wheel flanges.

In 1986 Transnet did tests to evaluate the effect of rail lubrication on energy consumption on curved track. A 200 meter radius curve in normal service was not lubricated until severe wear occurred on the high leg rail. Ten standard wagons of predetermined mass were run around the curve and the energy required to achieve the run was calculated. Immediately thereafter the curve was lubricated and the test repeated with the same wagons. Under the dry, un-lubricated curve conditions, the wagons required 54 Newton/ton to traverse the curve. When the coarsely worn rail was lubricated, only 28 Newton/ton was needed to run around the curve. In this case, 48% less energy was sufficient to haul the load around the curve." (8. McAlister, 1986) This figure will differ for different radii of curve, but the principle applies to railways everywhere. A saving of 28% in power usage was reported on the Richards Bay Coal Line under normal operating conditions, partly because of rail lubrication, and it was reported that "a good correlation was found to exist between energy usage and track lubrication.”

Adequate rail lubrication results in an increase in tonnage ratings where train length, load and composition are controlled by curve length and radius. This implies that 10% to 20% additional wagons can be hitched to a train for the same tractive effort when the line is consistently and properly lubricated.

5.6.1.2 Chain wear

Chain drives are widely used in industry and in motorcycles. Excessive friction due to poor maintenance in a typical chain drive increased energy consumption by 19%, and at the same time the energy transferred was reduced by 20%, thus overall efficiency was reduced by 33%.

5.7 Failures

Root cause failure analysis is not typically performed in industry, hence the true value of lubrication related failures cannot be determined. There are however a number of individual operations that are conducting root cause analyses and have reliability engineers for failures above a certain value.

Most failures and breakdowns that occur are typically due to:

- Contamination, water or dirt ingress
- Alignment
- Poor maintenance
- Not greasing / lubricating
- Policies and control

The major component failures are gearboxes, pumps and bearings. A high number of valves also fail due to highly corrosive fluid that is used in certain industries.

Typically up to 35% of the failures are caused by shaft misalignment. Laser alignment equipment is normally available, but is not always used by the maintenance personal, unless the reliability department insist, and check that this occurs. An example in one plant was fans with double spherical bearings that were failing: 30% were due to misalignment and 70% due to balancing. Bearing life in the 18 fans was 2-3 months. With correct alignment and balancing this was reduced to approximately one failure per annum.

These failures indicate the lack of skills, attitudes and training of artisans and artisan helpers. It is believed that this could be the cause of up to 60 -70% of all failures.

The majority of enterprises have a production at all costs philosophy, where scheduled services are missed or ignored due to production pressure; this often results in increased wear rates and down time due to failures.

Certain industries experience high annual turnover of gearboxes of up to 35%, this is mainly in areas where high dirt ingress is experienced which cause bearing failures, while in other, cleaner parts of a plant, gearboxes may last 15- 20 years in service. This project has shown that after gearboxes have been retrofitted with suitable breathers, and where possible a filtration system, no further failures were experienced.

An example noted during this project was a gearbox failure caused by a lack of lubricant because the gearbox was not serviced; it was situated in a pit and could not be accessed with the plant running. Six hours of production valued at approximately R440 000 were lost due to this failure.

5.8 CONDITION MONITORING

Condition monitoring is a critical element in understanding the health of machinery in a plant, and an essential part of any maintenance program to reduce costs.

The condition of a machine can be monitored in many ways, often used in combination with each other, they normally include:

- Oil Analysis (off site) – no additional trending or tracking is used

- Infra Red (thermography), mainly for electrical failures
- Vibration on critical equipment only
- Physical inspections may be conducted on gears during shutdowns / repairs to monitor the wear rates of large gearboxgears; gear tooth condition is generally recorded by photographs

5.8.1 Vibration Analysis / Monitoring

There are a number of advantages of using vibration monitoring to determine plant status, however this needs to be done on a regular basis and tracked and trended. Many establishments previously conducted in house condition monitoring, principally through vibration analysis, but due to manpower and short term financial constraints this has been stopped and now, if conducted, it is only conducted on critical equipment. Although it is recognised that vibration analysis and other condition monitoring programs prevented breakdowns, the cost savings generated by these programs were not typically monitored.

6 SKILLS

On a technical level there is a perception that artisans have a general lack of knowledge and experience in maintenance skills, which appears to be related to a shortfall in mentoring and apprentice and technical training. At the same time the technical management strata in an organisation typically consists of graduate engineers, who by the nature of their training have no practical experience. As artisans are promoted within an organisation this overall lack of skills becomes entrenched.

While there is a general lack of skills in maintenance staff, the complexity of equipment has increased, thus previous standards of knowledge no longer apply, and staff who are not trained in more modern and complex equipment lag further behind in skills and knowledge.

Maintenance skills depend both on a sound initial training and mentoring, and continuous training in new concepts, practices and equipment, such as is recognised and required by the Engineering Council of South Africa (ECSA).

This study has shown that, in general, equipment life has been reduced by a factor of three over the past 15 to 20 years, and that the causes of this reduction are a lack of traditional maintenance skills:

- That dirt does not lubricate
- That shafts must be correctly aligned
- That oils / greases are not all the same

Within an organisation, different aspects and levels of the same basic technical knowledge must be known and used at many different locations in the organisation, for instance:

- Senior Management must understand the concepts of friction and wear within tribology to correctly empower the organisation to make sound use of these concepts.
- Engineering Management must understand and implement the correct aspects of tribology to ensure that overall operating maintenance costs and energy consumption are minimised.
- Production management are usually responsible for the greater part of the energy budget, and must understand and implement the correct aspects of tribology to ensure that energy consumption is minimised.
- Purchasing must understand the difference between ‘cheap’ and ‘value’ – often a more expensive product gives significantly reduced operating costs.

- Technical staff must understand the difference between lubricants; that lubricants and tribology materials are not all the same, and each has its specific place.

- Lubricators must know the difference between different lubricants, and how to correctly apply lubricants.

This study has found the following:

- Most senior managers have not heard the word tribology, but have a clear concept that operating costs must be minimised to make an organisation profitable. Maintenance forms a relatively small but important part, about 6%, of an organisation's budget, and lubrication forms about 1 to 4% of an organisation's maintenance budget, or about 0.24% of turnover. Being such a small part of the budget does not build any enthusiasm for knowledge in this aspect, but correct lubrication affects the condition of all lubricated equipment, and failure of that equipment, or certainly critical equipment, will have a negative effect on plant availability, even putting the organisation out of business. A lack of correct lubrication can have an exponential effect on energy consumption, plant availability, and organisation turn over.

- Tribology is typically not covered in graduate or tertiary level engineering course in South Africa, although aspects of maintenance, and that equipment should be lubricated, are covered. Reference to standard graphs for lubricant viscosity may be covered, but no mention is made of other lubricant qualities. No correlation is made between tribology and its ability to control or reduce friction and wear.

- Tribology is not covered at apprentice schools or universities of technology, although in some cases it is mentioned that equipment must be lubricated, without covering the qualities of different lubricants.

- Because tribology is not generally clearly understood, in some instances training is being conducted by self styled "experts" who do not necessarily have the required knowledge of the fundamentals of tribology.

- There is limited understanding of the role that viscosity plays in the efficiency of a machine. This extends to tertiary education as well.

- Hearsay or sales talk may be used to promote products and equipment, such as lubricants, which may be an improvement in the process, but not necessarily the best option for a specific plant or application.

- It is widely accepted that South Africa's artisan shortage is a chronic problem and that the training initiatives to build a new group of artisans have thus far failed to fully address the backlog. However there is light at the end of the tunnel and the newly formed Department of Higher Education and Training is addressing these issues.

- A question that remains unanswered however is: What level of tribology training will be included in future artisan standards?

- There are current pockets of excellence, where some industries and training concerns are addressing tribology at a fundamental level. Examples of this are Eskom, Anglo American and the South African Institute of Tribology

There is a deep fundamental lack of knowledge, from the CEO to senior management to artisan level on the role that tribology plays, not only in providing basic lubrication, but in the overall economy and health of an organisation. A significant need to improve skills at all levels across industry exists; however the skills imparted must be appropriate, and enhance the trainee's ability to be more effective. 'Training' often has a negative connotation, which is seen as a waste of time; trainees need to understand the impact of doing or not doing something.

A task force should be established to develop the required curriculum from school to tertiary level and from the general factory worker to the CEO's.

6.1 Case study on a lack of skills

A recent incident occurred when a multi load bulk lubricant tanker was dispatched to an open cast mine to deliver bulk loads of two different lubricants. The wrong product was pumped into the engine oil tank, and although the driver realised the mistake, he thought that he would "fix" the problem by ensuring that the correct volumes were pumped into the respective tanks. Both mine bulk tanks then contained various mixtures of lubricant, but the driver's paper work balanced. Unfortunately, due to the significant differences between the lubricants, the mine was brought to a standstill, as all vehicles that had received services or top-upsneeded to be drained. Fortunately, however, the error caused a rapid increase in blow-by on some trucks, or the incident would have been significantly more severe. The cost of this incident in lost production and equipment repair costs was approximately R3 million; this could have been resolved for a few thousand Rand if the driver had had the skill and knowledge to determine the mistake initially. Additional costs are now being incurred to prevent further multi load deliveries, and each lubricant delivery needs to be tested on site.

7 FUTURE PROJECTS AND RESEARCH

As there is currently a lot of research being conducted internationally in the area of tribology, this information needs to be channelled to the specific needs of South Africa and implemented, rather than being reinvented here. It is critical that international liaison is maintained with countries that are focusing on improving tribological practices, with the intention to improve energy efficiency.

7.1 Sharing ofbest practice

A centre of excellence must be establishedto share best practice and solve common industry tribology problems. This could also be used to co-ordinate industry data with regards to improvements made

7.2 Potential research projects

- Tribology is elevated from being a problem that is addressed in the workshop to one that MUST be addressed in the board room down to the workshop floor.
- MQL is a proven technology for non ferrous metals. Research is required to develop this technology for ferrous metals.
- Conveyers – efficiency in terms of operation and maintenance practices of roller selection, monitoring and optimisation
- MEHF use in hydraulic equipment, both mobile and industrial
- Correct viscosity in electric motors
- Multigrade energy efficient engine oil
- Friction Modified fuel
- Rolling resistance (tyres & road surfaces) – implementation of international best practice, for South African conditions.
- New tribo materials and surface engineering techniques, for specific applications, such as, medical, wear material in mining and sugar mills and any beneficiation process.
- Hydraulics – understanding of losses in pumps, control systems, pipes, valves etc., and the effect of viscosity.

- Condition monitoring and failure investigation – critical – need to see the big picture.
- Relubrication and drain interval optimisation.
- Root cause failure analysis on a national basis is critical in understanding the areas of development and needs for future research.
- How to transfer international and local best practices between industries for efficiency improvements.
- Standards development (lubricants, wear material and equipment, such as hydraulic hoses) and implementation and monitoring – what is the best way to protect the consumer?
- Cradle to grave – best use of the products and minimal consumption and appropriate disposal. The potential of biolubricants and synthetic lubricants to reduce disposal costs
- Base stock recycling
- Bio based lubricants
- Hydraulic leak detection and extending hose life

Establishing a Research and Development University Chair would promote Tribology and could be used to conduct R&D that is specific to South African conditions

8 CONCLUSIONS

Tribology should be recognised and supported across industry from the boardroom to the shop floor, but this study has found that, if considered at all, it is most often considered to be lubricant related, which is a commodity function relegated to the lowest level of labourer.

Unfortunately, all the information required to perform this study was not available from the industry sectors, as most were not monitoring their energy usage, costs and the cost impact caused by tribology. This in itself is very interesting and concerning, and shows that the relevance of tribology is not clearly known or understood. It is difficult to generalise across the entire South African market, as there were pockets of excellence within the different industries. However, certain areas of information can be extrapolated across industry as a whole, these are highlighted in the report, as are proposed research areas and areas for further work and or consideration.

Throughout South Africa there are pockets of excellence and pockets of the blind leading the blind, sometimes in the right direction, and pockets of people who are lost. Through this project it is hoped that tribology becomes a cornerstone of industry at large, to the overall benefit of all South Africans.

To place tribology in its true place in industry the following should be considered:

- There is a desperate need to get back-to-basics:
    - A need to calculate the correct viscosity grades throughout to minimise energy wastage
    - To understand the difference between grade and type of lubricant
- Education is a priority, from the boardroom to labourer level. Tribology is currently not part of any tertiary level course
- Total cost of ownership of assets should be a philosophy that is implemented
- Filters and filter management is CRITICAL in improving system cleanliness and improving component life

- Design of systems from an operation and maintenance perspective is critical to minimise dirt contamination of systems during maintenance

- The lubricator is probably the MOST important person on the plant, and should be trained and recognised accordingly

- Tribologists are required in all industries particularly in production and design to ensure that equipment is correctly designed, produced and operated. This will ensure that the benefits of correct tribology are considered and harnessed

REFERENCES

[i] www.enatis.com/images/stories/statistics/livevehpopulationvehclassprov20100331.pdf

[ii] Sasol Synthetics training course – SAE 780984

[iii] Discussions with gearbox manufacturers

[iv] RohMax presentation

[v] Machinery Lubrication

General consultations with industry, original equipment builders, lubricant marketers and lubricant component suppliers