LUBE-TECH

NO.32

TRIBOLOGY BASICS

This article is primarily intended at those who are involved in some way in the lubricants industry and have a limited technical knowledge, but would like to learn more.

These days one cannot be involved in the lubricants industry for very long before one encounters the term 'tribology'. What is it and what does it mean exactly?

DEFINITIONS

'Tribology' is a term that has been relatively recently introduced and is derived from the Greek word 'tribos' which generally means 'friction, rub, grind' or 'to wear away'.

Tribology is briefly described as being the 'Science and technology of interacting surfaces in a state of relative motion and the practices thereto'. This very broad scope embraces in detail the processes of friction, lubrication and wear in all mechanical contact situations. Tribologists are concerned with optimum machine design and maintenance programmes leading to improvement in service life, safety and reliability. A successful tribological approach is critical to the economics and operational reliability of industrial manufacture and processing.

In addition to the word 'tribology' there are a number of other closely-related terms which involve these general principles in some way or other.

'Nanotribology', for example, is a sub-field of tribology involving contact geometries on the icro scale which are well-characterized at atomic length or time scales. These tend to be on the order of nanometers and nanoseconds. However, while tribological interactions often occur in very small scales and volumes, observations to date have been limited to large-scale dimensions and volumes due to limitations of equipment and techniques.

With a virtual revolution in electronics and materials technology, we are now able to make reliable measurements down to nano and pico metric levels. This advance coupled with the giant strides in non-continuum modeling at the molecular level has opened up a new world of phenomenon, properties and mechanics. This enables fresh look at old problems such as lubrication and hardness while it brings in new approaches to design of materials and components for tribological applications. The problems of nano wear in magnetic storage disc has now been handled successfully using the tools of nano tribology. To look into the immediate future, the problems of ultra thin tribological coatings and designer molecules for specific applications look solvable within the framework of nano tribology.

Others terms include:-

'triboelectric', an electrical charge produced by friction between two objects; such as, rubbing silk on a glass surface.

'triboelectricity', in physics, electrical charges produced by friction between two surfaces; static electricity.

'tribofluorescence', 'triboflurescent'; to give off light as a result of friction.

'tribologist', a specialist in the science of tribology.

'triboluminescence', the quality of emitting light under friction or violent mechanical pressure.

'triboluminescent', exhibiting triboluminescence.

'tribophosphorescence', 'tribophosphorescent', to produce light by friction.

'tribothermoluminescence', 'thermoluminescence' (luminescence resulting from exposure to high temperature) produced in a material as a result of friction.

'tribometer', an instrument for estimating sliding friction.

'tribophysics', the physical properties or phenomena associated with friction.

'tribophosphoroscope', an instrument for examining triboluminescence.

More familiar terms in common use include e.g. 'tribulation', originally from the Greek; then through Latin, "to press; affliction"; distress, great trial, or affliction.

RECENT HISTORY OF TRIBOLOGY

The term Tribology was first defined in 1966 in a report (Lubrication (tribology) education and research, Department of Education and Science, HMSO (1966)), and the term subsequently gained more wide-spread recognition and general acceptance following its promotion by Mr. (now Professor) H. Peter Jost; the original paper being now known as the 'Jost' report. In retrospect, this paper, which discussed technological and economic aspects of the lubrication and wear of machines in a national context, is now regarded as having been a ground-breaking document of enormous significance. It highlighted that significant economic savings could be achieved in a number of important industrial sectors in British industry by applying sound tribological practice.

Although the name tribology is new, the constituent parts of tribology i.e. friction, and wear, coupled with lubrication are as old as history. The economic implications alone of tribology are enormous, and investigations by a number of countries arrived at figures of potential savings of 1.0% to 1.4% of their respective GNPs, obtainable by the application of tribological principles, often for proportionally minimal expenditure in Research and Development.

In addition to the enormous economic significance of the application of proper tribological principles are the environmental benefits. The reduction in friction and wear rates result in consequential savings in energy and materials which when translated onto a global scale, are enormous. Even relatively small improvements in individual items, such as the use of lower viscosity or friction-reducing oils as crankcase lubricants, are extremely important on a global scale due to the huge numbers of vehicles potentially involved.

It is interesting that, since the original publication of the Jost report, there has been a major shift in the interpretation of the major benefits arising from the implementation of sound tribological principles. The original report identified that the most significant economic savings could be achieved by reducing costs associated with maintenance, but subsequent studies in other countries identified that cost savings arising from reduced consumption of energy and materials were beginning to play a more significant role as environmental issues became increasingly important.

Since the 1980's further developments in the recognition of global pollution and the impact of the overuse of finite sources of raw materials have focused even more attention on tribology.

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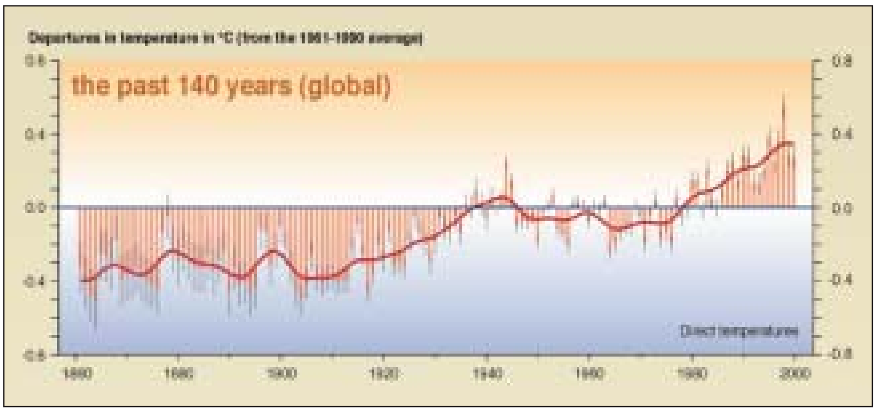
The introduction of legislative control and taxation measures, notably in the USA and in Europe, to curb pollution, have concentrated efforts in reducing energy consumption. Such was the impact of the original Jost report, and the increased recognition of the importance of tribology, that three National Centres of Tribology were set up over 30 years ago in the UK, at Leeds, Swansea and Risley. They continue to operate providing a range of tribological training, testing, and consultancy serices to industry, and also providing information to their clients on all problems relating to lubrication, friction and wear. In spite of all this, the subject has generally received little recognition at Higher Education level in terms of offering tribological exposure on a routine basis to engineering degree students, although the subject is attracting greater interest at post-graduate and research levels.

TRIBOLOGY AND POLLUTION/GLOBAL WARMING

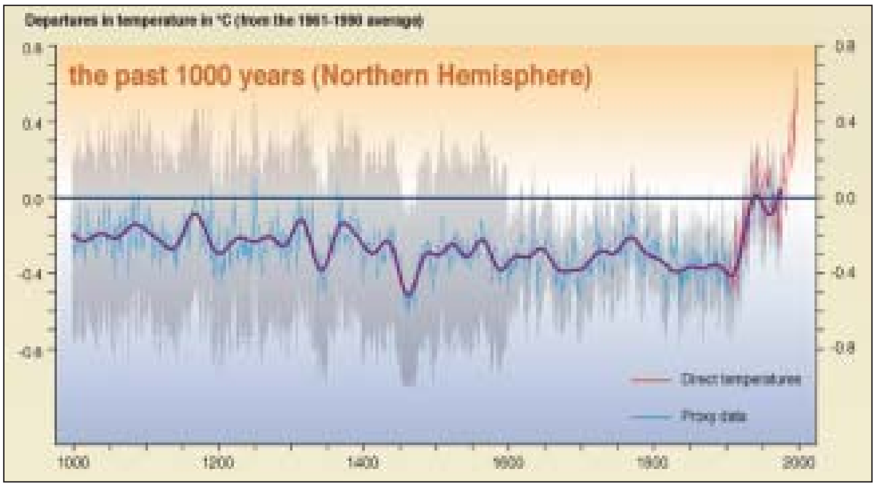
The Intergovernmental Panel on Climate Change (IPCC) has been established by WMO and UNEP to assess scientific, technical and socio- economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation. It is open to all Members of the UN and of WMO.

Their Third Assessment Report (WG1) ‘Climate Change 2001’ contains the results of a comprehensive assessment of studies around the world. From the observations made, a number of conclusions can be drawn which have already been well-publicised, and are repeated again for emphasis.The global average surface temperature (the average of near surface air temperature over land, and sea surface temperature) has increased since 1861. Over the 20th century the increase has been 0.6 ± 0.2°C ***(Figure 1a)***. This value is about 0.15°C larger than that estimated by the SAR for the period up to 1994, owing to the relatively high temperatures of the additional years (1995 to 2000) and improved methods of processing the data. These numbers take into account various adjustments, including urban heat island effects. The record shows a great deal of variability; for example, most of the warming occurred during the 20th century, during two periods, 1910 to 1945 and 1976 to 2000.

Variations of the Earth’s surface temperature for:
(a) the past 140 years



(b) the past 1,000 years



- Globally, it is very likely that the 1990s was the warmest decade and 1998 the warmest year in the instrumental record, since 1861.
- New analyses of proxy data for the Northern Hemisphere indicate that the increase in temperature in the 20th century is likely to have been the largest of any century during the past 1,000 years. It is also likely that, in the Northern Hemisphere, the 1990s was the warmest A and 1998 the warmest year ***(Figure 1b)***. Because less data are available, less is known about annual averages prior to 1,000 years before present and for conditions prevailing in most of the Southern Hemisphere prior to 1861.
- On average, between 1950 and 1993, night-time daily minimum air temperatures over land increased by about 0.2°C per decade. This is about twice the rate of increase in daytime daily maximum air temperatures (0.1°C per decade). This has lengthened the freeze-free season in many mid- and high latitude regions. The increase in sea surface temperature over this period is about half that of the mean land surface air temperature.

Temperatures have risen during the past four decades in the lowest 8 kilometres of the atmosphere.

- Since the late 1950s (the period of adequate observations from weather balloons), the overall global temperature increases in the lowest 8 kilometres of the atmosphere and in surface temperature have been similar at 0.1°C per decade.
- Since the start of the satellite record in 1979, both satellite and weather balloon measurements show that the global average temperature of the lowest 8 kilometres of the atmosphere has changed by +0.05 ± 0.10°C per decade, but the global average surface temperature has increased significantly by +0.15 ± 0.05°C per decade. The difference in the warming rates is statistically significant. This difference occurs primarily over the tropical and sub-tropical regions.
- The lowest 8 kilometres of the atmosphere and the surface are influenced differently by factors such as stratospheric ozone depletion, atmospheric aerosols, and the El Niño phenomenon. Hence, it is physically plausible to

expect that over a short time period (e.g., 20 years) there may be differences in temperature trends. In addition, spatial sampling techniques can also explain some of the differences in trends, but these differences are not fully resolved.

Snow cover and ice extent have decreased.

- Satellite data show that there are very likely to have been decreases of about 10% in the extent of snow cover since the late 1960s, and ground-based observations show that there is very likely to have been a reduction of about two weeks in the annual duration of lake and river ice cover in the mid- and high latitudes of the Northern Hemisphere, over the 20th century.
- There has been a widespread retreat of mountain glaciers in non-polar regions during the 20th century.
- Northern Hemisphere spring and summer sea-ice extent has decreased by about 10 to 15% since the 1950s. It is likely that there has been about a 40% decline in Arctic sea-ice thickness during late summer to early autumn in recent decades and a considerably slower decline in winter sea-ice thickness.

Global average sea level has risen and ocean heat content has increased.

- Tide gauge data show that global average sea level rose between 0.1 and 0.2 metres during the 20th century.
- Global ocean heat content has increased since the late 1950s, the period for which adequate observations of sub-surface ocean temperatures have been available.

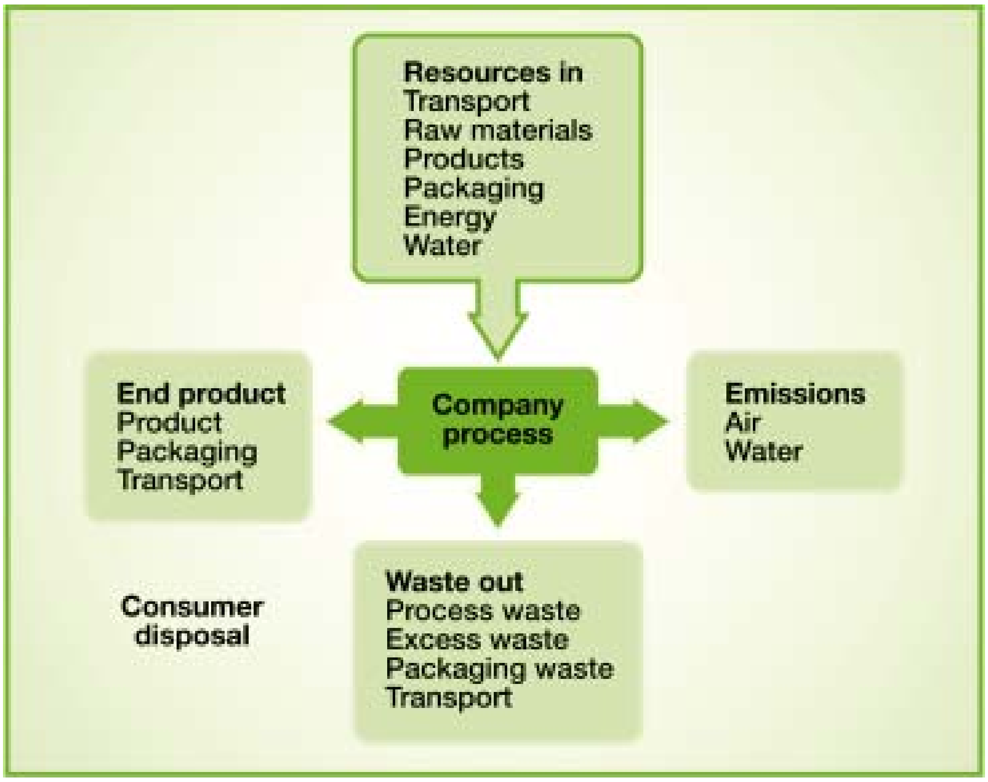
Mathematical 'modelling' of climate changes are enabling us to predict future changes with more and more accuracy. Models are simply formal expressions of processes and how they fit together, and are absolutely dependent upon the acquisition of high-quality data. Models of physical processes in the ocean and atmosphere provide much of our current understanding of future climate change. They incorporate the contributions of atmospheric dynamics and thermodynamics through the methods of computational fluid dynamics. This approach was initially developed in the 1950s to provide an objective numerical approach to weather prediction. It is sometimes forgotten that the early development of "supercomputers" at that time was motivated in large part by the need to solve this problem.

From the WG1 report there is abundant evidence to show that the earth is heating up at an unprecedented rate at the moment. The reasons for this occurrence are less well defined since, although it is popularly supposed that the main cause is the increase in the generation of greenhouse gases due to mans activities, there are some anomalies in the argument, e.g. the fact that the earths temperature actually reduced during the period between 1940 and 1980. However, unprecedented efforts are now being directed at reducing the generation of greenhouse gases, carbon dioxide in particular, and, in this climate of increasing environmental awareness and desire for improvement, any perceived rectification measures will receive strong support. In this context, the subject of tribology and the application of good tribological practices can only become progressively more important with time.

TRIBOLOGY AND ENERGY ECONOMICS

Factors which need to be considered when estimating the various costs arising from a process can be represented by Figure 2.

Figure 2



It has been calculated that financial losses which are accountable to friction and wear represent around 4% of gross national product (GNP) for developed countries and that potential savings of around 1% GNP remain a viable target. It has also been estimated that the ratio of 'expenditure on research to savings' is around 1:50 which should be regarded as so highly favourable as to open the flood-gates to a massive increase in research into tribology.

Those involved in the lubricants industry know full well that many lubricant purchasers choose to ignore good advice and continue to operate purchase policies based on price rather than performance in spite of the wealth of information from various cost/benefit analyses to the contrary. It is an undeniable fact that the benefits arising from the use of high-quality lubricants in terms of reducing energy consumption, increasing component life and reducing maintenance frequencies are becoming more and more important issues, and the merits of high-quality lubricants are likely to be increasingly highlighted as assessment and evaluation programmes become increasingly sophisticated. One such approach is described below.

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TOTAL TRIBOLOGY

The use of the term 'total' is becoming increasingly familiar in other areas, e.g. as 'total quality management', to imply a wider and more comprehensive approach to the subject compared to the approach adopted previously. Such is the meaning in this case, where the concept of 'total tribology' emphasises that good tribological practice should be applied at all stages of the life cycle of the interface components of a machine or product in order to maximise cost savings. This total view should encompass concept, design, manufacture, use, storage and disposal of engineering components, complete systems, and consumables.

However, in spite of the valiant efforts of organisations such as The Tribology Group of the Institution of Mechanical Engineers into promoting the 'total tribology' concept in order to achieve more widespread recognition, progress to date has been rather slow.

However, during the last 30 years or so, a new methodology (Life Cycle Analysis or Life Cycle Assessment, LCA) has been developed which aims to quantify the impact of products or processes on 'costs', although in his case the environmental as well as the social 'costs' are considered in addition to the purely economic variety. Such costs are carefully considered for each life cycle stage of the development, manufacture, use and disposal of a product. Although the concept is still relatively new, and is still being further refined, it has already yielded much useful information, and also a few surprises, e.g. recycling options, normally advocated by environmental pressure groups, are not always the best overall solution.

The various stages of a product's lifecycle together with their respective associated 'costs' may be summarised as follows:

Activity	Associated 'costs'
Design	Design Tools + human endeavour
Tribo-testing of prototype	Energy + materials + emissions + waste
Manufacture	Energy + materials + emissions + waste
Operational Use	Energy + materials + emissions + waste (service and maintenance)
Disposal or recycling	Energy + materials + emissions + waste

The relative simplicity of the above summary disguises the complexity of the overall calculations and the enormous amount of data necessary to obtain meaningful information. Although some 'costs' such as those related to the collection of raw material and to manufacturing, in practice they can often form a complex interactive web, with many secondary effects. The concept of total tribology should be an essential element in quantifying such overall 'costs'

TRIBOLOGY AND THE LUBRICANTS INDUSTRY

Those involved in the lubricants industry are becoming increasingly aware of the importance of the tribological principles involved in the application of lubricants in both industrial and automotive applications. Those involved in the design of machines and mechanical equipment are now realising that it is becoming increasingly essential to ensure that the lubrication aspects are incorporated into the overall design philosophy from the beginning.

In addition to the environmental and economic benefits, we can now readily accept that in our daily lives the safety aspects of proper lubrication, maintenance programmes, equipment design and materials of construction cannot be ignored. Many injuries and even deaths involved in such areas as railways, conveyors and many others, could have been avoided had tribological good practice been followed in design and operation.

Further, the average lubricants technologist will in all probability not yet appreciate the enormous numbers of other areas where the application of tribology is at least equally, if not even more essential. In today's world relying as it does on computers, tribological failure of magnetic storage system would have catastrophic consequences. Tribologically-caused unreliability in aerospace and marine activities would not only be extremely expensive but also risk human lives. The tribological aspects in medical engineering are crucial to prevent unnecessary pain, suffering - even death. In this field of medicine, the development of the artificial hip-joint in particular posed an interesting tribological problem. It has often been argued that in the whole field of manufacturing and service industries, lubricants are involved in some way or other in practically every operation. The same is even more true of the application of proper tribological principles, since their sphere of relevance is considerably broader than a consideration of purely the lubrication aspects.

(This article is intended to introduce the reader to the basic concept of tribology. It is intended to follow this article with others which deal with the fundamentals of tribology, namely, lubrication, friction and wear, in greater detail in later issues of Lube-Tech).

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