

## TRIBOLOGY BASICS (continued from LUBE-TECH No.32)

### LUBRICATION

To the layman, the term 'lubrication' probably immediately brings to mind up the use of an oil to ease the movement between two surfaces. Whilst this basic concept is undoubtedly right enough, in reality the term 'lubrication' can mean a great deal more. For example, the lubricant does not necessarily have to be a fluid, but can also be a solid, (either in powdered form such as graphite or molybdenum disulphide or as a continuous layer such as PTFE), a semi-solid such as grease, or even a gas.

### FLUID LUBRICANTS

Also, the actual lubricant mechanism of conventional fluid lubrication can be grouped into a number of categories, known as 'regimes', the most common being HYDRODYNAMIC, ELASTOHYDRODYNAMIC, and BOUNDARY lubrication.

### HYDRODYNAMIC LUBRICATION (HD)

Basically, HD occurs when the moving surfaces are completely separated by a continuous film of lubricant (Fig.1).

Figure 1

### Hydrodynamic Lubrication

Movement of the block increases a hydrodynamic wedge of oil which supports the load.

The wedge collapses if the oil is too thin or the sliding speed too low.



The upper block 'floats' on a wedge-shaped film of oil, which is thicker at the front end of the moving block. In practice, the more common application of fluid lubricants is for the lubrication of plain bearings (Fig.2).

Figure 2

### HD lubrication of plain bearing



The shaft rotating in a bearing housing pulls the liquid lubricant into a conical converging clearance between the bearing shell and shaft.

The pressure on the lubricant increases as the lubricant film thickness increases.

Although HD can occur if such a bearing is merely immersed or 'splash' lubricated with oil, in practice it is normal to feed pressurized lubricant into the bearing using a separate lubricant pump. By ensuring a copious supply of pumped lubricant, the bearing will function at higher loads and rotational speeds without the lubricant film breaking down.

It is interesting that the localized fluid pressure within the bearing is far higher than the load on the bearing itself. This effect was first observed by Tower in 1883. Reynolds, in 1886, attributed this phenomenon to the formation of a hydrodynamic liquid film by the rotating shaft, which 'pulls' the liquid lubricant into the conical converging clearance between the bearing shell and the shaft and thus creates the dynamic pressure which supports the shaft.

For a true state of HD to be maintained, it is essential that a continuous film of lubricant fully separates the moving surfaces. The thickness of the fluid film can be affected by a number of factors, e.g.

If the pressure between the moving surfaces increases, there will be a greater tendency for the oil to be squeezed out of the bearing

If the temperature increases, this will effectively reduce the viscosity of the oil, again increasing its tendency to leak from the bearing

If a lower viscosity oil is used, this again will increase its tendency to leak from the bearing

If the rotational speed of the bearing is reduced, this will reduce the tendency to form an oil 'wedge', and will again reduce the thickness of the lubricant film.

It is obvious from the above that the greatest wear in a bearing will occur at the time of start-up at a point where the bearing starts to rotate, but before the lubricant film has a chance to become fully established. It is well known that car engines, for example, which are subjected to frequent short journeys wear at a far higher rate than those which are routinely used for longer journeys only.

In high-speed bearings subjected to high loads (e.g. in turbines or generators) a higher viscosity lubricant is often used during start-up periods, which is then substituted for a lower viscosity lubricant once normal running conditions have been achieved, since continued use of the higher viscosity oil would result in losses in efficiency due to higher bearing temperatures. Another approach to combating start-up wear and maintaining adequate lubricant film thickness is to use a hydrostatic lubrication system, where an auxiliary lubricant pump located outside the bearing is used to create the lubricant pressure required to separate the sliding surfaces in the bearing, the pressure can then be adjusted independently of the relative speed of the sliding surfaces, even when they are stationary.

However, there is always the possibility of a situation where external factors can progressively act to reduce the lubricant film to critical limits, and to a point where the continuous film is on the point of breaking down, allowing metal-to-metal contact between the sliding surfaces. At this point, another mechanism takes over, known as elastohydrodynamic lubrication (EHD).

At this point, two other effects occur, both of which act to maintain the necessary lubricant film.

1. Due to the enormous pressures which begin to occur at this stage, the asperities, or peak tips, of the metal surfaces start to flatten out, and therefore the bearing surface area is increased.

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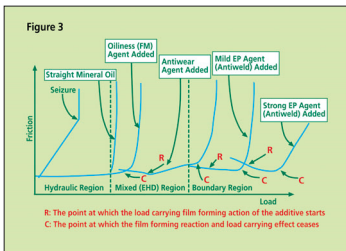
2. At the same time, the lubricant undergoes a large temporary increase in viscosity, which also assists in maintaining the lubricant film.

These conditions are more commonly encountered in rolling-type bearings, as opposed to plain bearings, since localized pressures are much higher in the former than in the latter. The bearing load has little effect upon the film thickness because at the pressures involved the lubricant film is actually more rigid than the bearing surfaces. Any increase in load will therefore deform the surface asperities even further, thereby increasing the bearing surface, rather than reduce the film thickness.

However, there comes a point where even the EHD mechanism is incapable of maintaining a lubricant film. At this point, some limited metal-to-metal contact takes place, and the lubrication mechanism which then becomes effective is known as boundary lubrication. The friction between the sliding surfaces is then governed by:

the existence of any chemi-adsorbed layers on the metal surfaces and/or the presence of any surface-active additives in the lubricant which can form transient chemisorbed layers on the metal surfaces.

The progressive movement from hydrodynamic > elastohydrodynamic > boundary lubrication is shown in load vs. friction diagram (Fig 3).



From all of the above, it is obvious why properties of the lubricant itself are critical if satisfactory lubrication conditions are to be maintained.

The viscosity, and to a certain extent, the viscosity index of the lubricant is a major factor in maintaining an adequate film. Higher viscosities result in thicker and more stable lubricant films, but if the lubricant viscosity is too high, then excessive temperature rises can occur within the bearing, which can effectively reduce the viscosity of the lubricant to a lower value than would be the case where a lower viscosity lubricant had been used in the first place.

The nature and content levels of load-bearing additives become progressively more important as loads increase to a point where the lubricant film begins to break down and boundary lubrication conditions emerge.

Gaseous bearings, such as air bearings, can have a number of advantages over the use of more conventional fluids in certain applications, the major benefit probably being the extremely low friction, the only friction between due to the almost unmeasurably low shear force within of the air film. For example, a 20,000 lb.

Balance rotor can be turned by applying less than 1 g. force to a 10" moment arm. There is no 'stick-slip', allowing almost perfectly smooth slow speed motion. Because there is no contact, air bearings do not wear. They can be operated at speeds of up to 30,000 rpm with only a slight temperature rise due to the shear friction in the air film.

## SOLID LUBRICANTS

The most commonly-known of the solid lubricants is probably graphite, which has been used as a lubricant for ca. 150 years. The lubricating properties are due to its layered lattice structure; the weak Van der Waals forces between the carbon layers allow easy relative movement between the layers whilst the strong bonds within the layers resist the penetration of surface asperities through the layers. The low frictional properties are also in part due to adsorbed films (particularly water vapour) also acts to limit cohesion between neighbouring surfaces.

Another more recent commonly used solid lubricant, molybdenum disulphide, has a lamellar structure, with the molybdenum layers 'sandwiched' between sulphur layers, which in many ways is similar in its behaviour to that of graphite. Again, the weak Van der Waals forces between the sulphur layers permit easy relative movement of the lamellae over each other. The strong bond between the molybdenum and the sulphur again resists any penetration by surface asperities.

Other lesser-known solid lubricants include borax, cadmium chloride, boron nitride, lead iodide, cobalt chloride, silver sulphate, zinc stearate etc.

Solid lubricants can be applied directly in powder form, as suspensions, pastes, anti-friction lacquers, metal films, incorporated into self-lubricating materials, as chemical surface layers or as plastics. Self-lubricating materials can include, e.g.:-

'Oillite' bearings where graphite can be incorporated into a sintered bearing metal, such as brass, by embedding the graphite into the brass during the sintering process.

'Free-machining' brasses containing lead which acts as a lubricant permitting the brass to be machined without the use of any other lubricant

They are used mainly in harsh environments, i.e.:-

Where loads are high and conventional fluid lubricants would be squeezed away from between the bearing surfaces

Where speeds are low and the surface asperities could penetrate liquid layers

Temperatures are extreme, both high and low

In environments which would wash away conventional oils and greases

In environments which are dirty or abrasive

In environments where maintenance is infrequent

Often used in the assembly of difficult-to-lubricate parts to prevent galling or seizing

Another harsh operating environment which brought to light the beneficial lubricating properties of lead were the operating conditions of the valves within the conventional internal combustion engine. Up to the time of the introduction of lead-free petrol, and the consequent problems with valve-seat recession, the role of lead, originally added as an octane-booster, in protecting the valve seats from wear had not been fully appreciated.

David Margaroni

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## HEALTH & SAFETY EXECUTIVE CHEMICAL ESSENTIALS : Practical Advice on Working with Chemicals

There are many legal requirements facing small businesses using chemicals in the workplace. They have to protect the health of employees, guard against fire and explosion risks and comply with environmental legislation on discharges to the air and water and waste disposal. These requirements are all necessary if society is to reap the benefits of chemicals, without suffering harm. They can be very confusing and time consuming for industry, especially small businesses. A few do not know that they have to try, and then society picks up the bill for accidents and pollution incidents. Most want to comply, but do not know where or even how to start.

Imagine a system that provides integrated advice covering the main legal requirements, tailored to businesses individual needs. You have imagined Chemical Essentials. For many processes that use chemicals or generate dusts and fumes, in a few clicks the users will be able to identify their own process and print out advice which tells them what they have to do to comply with health, safety and environmental law. The box below explains how the (imaginary) garage, Marvellous Motors, will be able to obtain the advice they need.

For common tasks, such as mixing, weighing or spraying chemicals or products containing chemicals, the user will only need to enter basic information on what they are using, and how, and the task they are carrying out. Behind the scenes the system will calculate the steps needed to store, use and dispose of the chemical or product safely and provide this advice as downloadable pdf files.

The development of the *Chemical Essentials* concept has been made possible by a £250,000 award from the Treasury's Invest to Save Budget. During the last three years, the Health and Safety Executive (HSE), Environment Agency (EA) and the Scottish Environment Protection Agency (SEPA) worked together to meld their respective legal requirements into a unified system of rules, which deliver integrated health, safety and environmental guidance. The rules, which will not be visible to the user, contain a complex series of decision trees that ensure the user gets the appropriate advice. An independent expert group has helped in the development and validation of these rules. They are now being made widely available

to encourage peer review by health, safety and environmental specialists.

HSE's *COSHH Essentials* ([www.coshh-essentials.org.uk](http://www.coshh-essentials.org.uk)) is an Internet tool that helps businesses control health risks from chemicals; *NetRegs* ([www.netregs.gov.uk](http://www.netregs.gov.uk)), a joint project of EA, SEPA and the Environment and Heritage Service Northern Ireland gives advice about how to comply with environmental law.

*Chemical Essentials* builds on this to deliver practical advice in a user-friendly format. The demonstration CDROM sets out how the system could operate and provides specimen guidance for selected chemicals and tasks. A range of small businesses with the spectrum of chemical uses will pilot the CDROM to make sure it is easy to use and that the guidance meets their needs.

Independent market research has shown small businesses want integrated health, safety and environmental advice. *Chemical Essentials* will meet this need, once funding has been found to develop the electronic system and it is freely available on the Internet. It will make it easier for small businesses to comply with the law, contribute to improved occupational health and reduce harm to the environment. *Chemical Essentials* is an excellent example of government departments and agencies working together to produce practical help for industry.

Marvellous Motors want to start respraying cars, but are unsure what precautions they need to take. HSE's Infoline telephone service directs them to Chemical Essentials. They find motor vehicle repair in the list of activities for which ready-made advice is available. They click on this and get a list of available sheets. In addition to information on control of isocyanates in paints, they find that it is bad practice to drain petrol from tanks over a pit. They print out the advice sheets and the summary of the advice; this reminds them they need to put the advice into action. Thus in as few as four clicks they get practical advice directly relevant to their work.

## MEET THE BLF METALWORKING FLUIDS PRODUCT STEWARDSHIP TEAM AT MACH 2004

MACH  
2004

### CATCH UP ON THE LATEST MANUFACTURING TECHNOLOGY

MACH 2004 which will be held at the NEC Exhibition Centre, Birmingham UK on 19-23 April 2004 is the UK's largest manufacturing exhibition and attracts over 30,000 visitors

The British Lubricants Federation Metalworking Fluids Product Stewardship Group (BLF MWF-PS) promotes Best Practice and works in support of metalworking fluid industrial end-users. BLF MWF-PS will have a stand at the forthcoming MACH 2004 and will be located in the Trade Association & Advisory Centre, Hall No 4, Stand No 4560/C. The BLF MWF PSG team will be promoting the Health and Safety

Executive initiative 'Metalworking Good Practice Guide', which sets out Best Practice for metalworking fluid users and will be one of the presenters on Friday 23rd April at MACH 2004's new series of back-to-back seminars.

The stand will be manned by members of the BLF Metalworking Stewardship Group, who are all directly involved with the manufacture of metalworking fluids and the component raw materials used in MWF formulations and they will especially welcome all lubricant end-users and members of the British Lubricants Federation. Don't miss out, take the time to come to Birmingham National Exhibition Centre, there is a wealth of new technology and key information for anyone involved in machine manufacturing.

# LUBE-TECH

## LUBE 58 LUBE-TECH EMISSIONS CORRECTIONS

The tables on this page replace those used as part of the article in LUBE 58, LUBE-TECH 31, which unfortunately contained omissions and errors on some lines.

We apologise for this mistake and have reproduced for reader's information, the corrected tables in full, for completeness.

**Table 2. Passenger Car Emission Standards**

Tier	Year	CO	HC	HC+NO <sub>x</sub>	NO <sub>x</sub>	PM
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	0.14 (0.18)
Euro 2, IDI	1996.01	1.00	-	0.70	-	0.08
Euro 2, DI	1996.01*	1.00	-	0.90	-	0.10
Euro 3	2000.01	0.64	-	0.56	0.50	0.05
Euro 4	2005.01	0.50	-	0.30	0.25	0.025

†Values in brackets are conformity of production (COP) limits.  
a - until 1999.09.30 (after that date DI engines must meet the IDI limits).

Tier	Year	CO	HC	HC+NO <sub>x</sub>	NO <sub>x</sub>	PM
Euro 1†	1992.07	2.72 (3.16)	-	0.97 (1.13)	-	-
Euro 2	1996.01	2.20	-	0.50	-	-
Euro 3	2000.01	2.30	0.20	-	0.15	-
Euro 4	2005.01	1.00	1.00	-	0.08	-

**Table 3. EU Emission Standards for Light Commercial Vehicles (Category N<sub>1</sub>), g/km.**

Tier	Year	CO	HC	HC+NO <sub>x</sub>	NO <sub>x</sub>	PM
Euro 1	1994.10	2.72	-	0.97	-	0.14
Euro 2, IDI	1998.01	1.00	-	0.70	-	0.08
Euro 2, DI	1998.01*	1.00	-	0.90	-	0.10
Euro 3	2000.01	0.64	-	0.56	0.50	0.05
Euro 4	2005.01	0.50	-	0.30	0.25	0.025

**Table 3. (Continued)**

Tier	Year	CO	HC	HC+NO <sub>x</sub>	NO <sub>x</sub>	PM
Euro 1	1994.10	5.17	-	1.40	-	0.19
Euro 2, IDI	1998.01	1.25	-	1.00	-	0.12
Euro 2, DI	1998.01*	1.25	-	1.30	-	0.14
Euro 3	2002.01	0.80	-	0.72	0.65	0.07
Euro 4	2006.01	0.63	-	0.39	0.33	0.04

Tier	Year	CO	HC	HC+NO <sub>x</sub>	NO <sub>x</sub>	PM
Euro 1	1994.10	6.90	-	1.70	-	0.25
Euro 2, IDI	1998.01	1.50	-	1.20	-	0.17
Euro 2, DI	1998.01*	1.50	-	1.60	-	0.20
Euro 3	2002.01	0.95	-	0.86	0.78	0.10
Euro 4	2006.01	0.74	-	0.46	0.39	0.06

Tier	Year	CO	HC	HC+NO <sub>x</sub>	NO <sub>x</sub>	PM
Euro 1	1994.10	2.72	-	0.97	-	-
Euro 2	1998.01	2.20	-	0.50	-	-
Euro 3	2000.01	2.30	0.20	-	0.15	-
Euro 4	2005.01	1.00	0.10	-	0.08	-

Tier	Year	CO	HC	HC+NO <sub>x</sub>	NO <sub>x</sub>	PM
Euro 1	1994.10	5.17	-	1.40	-	-
Euro 2	1998.01	4.00	-	0.65	-	-
Euro 3	2002.01	4.17	0.25	-	0.18	-
Euro 4	2006.01	1.81	0.13	-	0.10	-

Tier	Year	CO	HC	HC+NO <sub>x</sub>	NO <sub>x</sub>	PM
Euro 1	1994.10	6.90	-	1.70	-	-
Euro 2	1998.01	5.00	-	0.80	-	-
Euro 3	2002.01	5.22	0.29	-	0.21	-
Euro 4	2006.01	2.27	0.16	-	0.11	-