LUBE-TECH

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SPECIFICATION AND LICENSING SYSTEMS FOR ENGINE OILS - ENGINE DEVELOPMENTS AND IMPLICATIONS FOR THE LUBRICANT

INTRODUCTION

We are all aware of the burdens being placed upon today's generation of engine oils by the requirements, often conflicting, of the OEMs, by legislation and also by the vehicle owners. Stress levels on the lubricant have accordingly increased with the successive introduction of more demanding performance specifications and general expectations from the lubricant. A simple calculation to express stress in a semi-quantifiable form is given by the equation:

$$\text{Stress} = \frac{\text{Engine Power} \times \text{Oil Change Interval}}{\text{Oil Consumption} \times \text{Sump Capacity}}$$

This simplified approach does not fully take into account increases in stress due to higher operating temperatures, higher shear rates, higher localised loadings, etc., but it can readily be calculated that stress levels on the lubricant have increased by a factor of 50 or more since the 2nd World War. In all likelihood, the increased stress levels on the lubricants are even higher than these calculations would indicate. Associated with the increased expectations of the lubricants are increasing development costs, and the increasingly rapid turnover in new specifications reduces the time available for the lubricant developers, or in this case mainly the additive suppliers, to recoup their investment.

Vehicle designers are being required to achieve higher and higher standards of fuel efficiency, reduce vehicle emissions and increase vehicle service mileage intervals. The main drivers may therefore be summarised under the following general headings.

- Resource Utilisation
- Environmental Protection
- Customer Satisfaction

These requirements, which are all to a certain extent interlinked, are being achieved by developments in lubricants technology, in addition to developments in engine technology, materials technology and fuel technology.

Lubricant performance increases are largely achieved by developments in additive technology.

1. RESOURCE UTILISATION

In 1975, the US introduced a Corporate Average Fuel Economy (CAFE) system for vehicles, the purpose of which was to progressively reverse spiralling levels of vehicle fuel consumption, which had been not helped by the low levels of duty payable on US fuel. A subsequent relaxation in oil prices coupled with a lack of demand for small cars was followed by a degree of relaxation in the CAFE requirements, which were then subsequently tightened up again. Although the main intention was to encourage the production and use of smaller and more fuel-efficient vehicles, it was also appreciated that the selection of a suitable lubricant could assist in achieving improvements in fuel economy.

The accepted engine test method for establishing lubricant-related fuel economy improvements compared with a reference oil (Sequence VIB) imposes limits for fuel utilisation efficiencies for the test lubricant and also evaluates its ability to maintain this performance over prolonged periods of use (equivalent to 4,000 miles). In Europe fuel economies are now generally expressed in terms of litres of fuel used per 100 km. and the target for many manufacturers of small 'eco' cars is 100 km per 3 litres of fuel, i.e. the '3-litre' car. An alternative way of expressing fuel economy is in terms of CO_2 g/km and the European body ACEA has already requested a 'voluntary' commitment from vehicle manufacturers to reduce CO2 emissions to a fleet average of 140g CO_2/km by 2008.

Lubricants can directly improve fuel utilisation in two ways:

- Lower viscosity lubricants will reduce churning/pumping losses in the engine; gains here are especially evident during the 'warming-up' phase.
- The incorporation of friction-reducing additives, usually based on molybdenum, will also decrease frictional losses in the engine.

The use of lower viscosity oils, whilst simple enough in theory, presents in practice a number of problems for the lubricant formulator. In general, although lower viscosity oils are well capable of providing an adequate lubricant function in a system designed for their use, they are more volatile. This volatility causes an increase in oil consumption by evaporative losses via positive crankcase ventilation systems, which in turn increases emission levels and also the need for more frequent topping-up. Increased migration rates past the piston oil-control ring into the combustion zone again leads to increases in emissions. Progressive loss of the lighter components will also result in oil thickening, with consequent adverse effect on fuel consumption. In engines not designed for low viscosity oils, certain parts of the engine subject to high loads are likely to wear at an increased rate due to breakdown of the lubricant film, with the consequent transition from hydrodynamic to mixed/boundary lubrication conditions.

Since conventional mineral oils cannot achieve the desired combination of low viscosity and low volatility, newer high-performance crankcase oils are now being formulated from synthetic fluids, such as polyalphaolefins (PAOs), or on a series of products known as 'unconventional base oils' or UCBOs. These latter products originate from crude oil, as do conventional mineral oils. However, their manufacture involves additional new refining techniques such as severe hydrocracking or wax isomerisation which re-arrange the molecular structure to such an extent that the finished product has properties more akin to those of a pure synthetic oil, although at about 50% of the cost. Interestingly, at a recent ruling in the US, such UCBOs are now allowed to be termed 'synthetic', although being originally derived from crude oil.

The use of friction modifiers to reduce internal friction in the engine is becoming increasingly widespread, as the newer specifications for crankcase oils emanating from both the API and ACEA call for demonstrable and sustainable improvements in fuel utilisation efficiency compared with reference oils.

However, one problem area has emerged where such oils have been used in high performance four-stroke motorcycles, since these vehicles use the crankcase oil to also lubricate other parts of the drivetrain,

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including the clutch, starter mechanism, back-torque limiter, etc. Since these items require controlled frictional characteristics for proper operation, the presence of friction modifiers has resulted in problems during use. As a result, we have recently seen the development of new specifications and test procedures for this market to ensure that the frictional characteristics of the lubricant were predictable and within certain parameters. This is one example of the application of an inappropriate lubricant referred to earlier, and clearly shows the need for the OEM and lubricant manufacturer to collaborate during the design stage. The demand for motorcycles is expanding rapidly, especially in the third world countries. A move towards 'cleaner' four-stroke motorcycles is becoming more and more evident, and the development of a lubricant specifically for this market is not before time.

Other means of improving resource utilisation have centred on increasing engine efficiencies, many of the recent technological innovations requiring lubricant 'tailoring' for optimum benefit. Despite recent initiatives involving comparatively new technologies such as fuel cells, hybrid petrol/electric units etc, the conventional internal combustion engine powered by diesel or petrol will probably be the dominant power plant over the next few decades.

Some of the new approaches are described below, together with the implications for the lubricant.

COOLING ON DEMAND

This system, which is considerably more sophisticated than the normal mechanically-pumped and thermostat-controlled system, involves either the use of an electric water pump or a flow control mechanism in the engine cooling system which is governed by engine metal temperature rather than by engine speed. Rapid warm-up, reduced friction and increased fuel economy are the benefits, but the operating environment for the lubricant is more severe, involving higher temperatures for longer periods of time, with the increased possibility of evaporative losses and thermal degradation.

COMMON RAIL DIESEL INJECTION

This technology has also yielded significant improvements in fuel utilisation efficiencies, to such an extent that the use of such diesels will become even more attractive for light duty applications, since fuel efficiencies of 40% have been achieved, matching the best fuel cells. There were initially fuel lubricity problems associated with the use of low-sulphur fuels in high pressure petrol pumps and injector nozzles which have been since been overcome by additive treatment of fuels. Implications for the lubricant include fuel dilution, tighter piston rings with increased friction, higher combustion temperatures, more NOx generation, higher operating temperatures, and the requirement for compatibility with de-NOx catalysts or NOx storage devices.

DIRECT INJECTION SPARK IGNITION (DISI), OR GASOLINE DIRECT INJECTION (GDI)

These engines also promise significant gains in fuel utilisation efficiencies, although problems with exhaust after-treatment, increased bore wear and polishing and injector system cleanliness need to be more fully addressed. Some of these issues again place increased stress upon the lubricant, which will be subjected to higher operating and piston ring temperatures. Bosch has estimated that by 2007, 50% of all gasoline engines of the production line will be GDI-type. Although low sulphur fuel is required, its use has not caused the problems previously encountered in diesel engine injection systems.

VARIABLE VALVE TIMING (VVT) AND CAMLESS VALVE OPERATION

This is now becoming increasingly widespread, and the use of camless valvetrains, ideally suited to this technology, is likely to be widely adopted in the near future. Traditionally, conventional cam-operated valve trains have presented one of the major sources of internal friction within the engine, although partially overcome by the use of roller-operated cams. Cam systems have therefore presented the lubricant formulator with some of the more difficult problems, and the incorporation of electro-mechanical, electro-hydraulic or pneumatic valve operation will not only have implications on the design of the cylinder head together with its associated lubrications systems, but also on the lubricant itself. The International Truck and Engine Corporation has recently demonstrated a camless diesel truck engine which is claimed to address future emission regulation while providing improved performance, and they expect to be introducing this engine in the marketplace within three years. Without the need for cam-operated valve lubrication, with its particular need for specific anti-wear additives, lubricants could be better tailored to the satisfactory lubrication and heat transfer requirements in the engine block.

CYLINDER DEACTIVATION

In this system, certain cylinders become non-operational under light-load conditions. Such systems will become more feasible with camless valvetrains, although there is the potential for increased lubrication and wear problems in the cylinder bore/ring contact under transient conditions.

INTEGRATED STARTER/ALTERNATORS

These are likely to become increasingly used during the next decade, coupled with a move from the traditional 12 volt electrical systems to 42 volt systems. Significant fuel economy gains can be achieved through the use of instant stop-start engine operation, particularly in heavy and congested traffic conditions due to the elimination of engine idle whilst stationary. However, lubrication will become an important issue since the engine will experience greater transient friction conditions, with thinner films and a higher incidence of mixed lubrication conditions in bearings and cylinder bores. Some OEMs may endeavour to overcome start-stop lubricant problems by using a separate hydrostatic lubrication system, which provides a lubricant flow immediately prior to start up.

HIGHER TOP RINGS

Higher top rings in gasoline and diesel engine pistons aid piston crown cooling, particularly important since there is a general increase in combustion chamber temperatures. At one time, the top ring was normally positioned at ca. 10 mm. below the piston crown, but 3 mm. is more typical in today's advanced engines. Because of the severe temperature gradient toward the piston crown, movements of only a few mm. can take the piston rings and associated lubricant from an environment of 250°C to 350°C, with increased risk of lubricant degradation.

ALTERNATIVE FUELS

Fuels such as hydrogen, methanol, or biodiesel, etc., whilst having some advantages in certain situations, will have considerable implications on lubricant performance. For example, hydrogen is likely to react with the unsaturated and aromatic constituents of the lubricant, which must also have a high water tolerance, particularly under cold/short trip driving conditions. The use of methanol as a fuel in countries such as Brazil has been found to result in increased corrosion problems, and the anti-corrosion properties of the lubricant required augmenting. Biodiesel, normally consisting of the methyl esters of fatty acids derived from e.g. rapeseed oil, has been used with some success in limited trials, but is not likely to find extensive use due to costs, and supply inadequacies. In practical trials in the UK, fuel dilution of the crankcase lubricant presented a problem, although engine conditions were not optimised for this type of fuel in this particular case.

ALTERNATIVE POWER SOURCES E.G. HYDROGEN FUEL CELLS

These have been the subject of much investment and investigation for many years, but their widespread adoption is still dependent upon further technological development.

2. ENVIRONMENTAL PROTECTION

Road transport is responsible for a large proportion of many of the current atmospheric pollutants, although the effect and localised concentration levels vary widely across the country according to traffic levels, proximity of other polluting sources and prevailing meteorological conditions. In an effort to reduce pollution levels, a European programme of mandatory vehicle emission standards was first introduced in Dec 1992, and has been progressively implemented ever since. Regulated emissions covered carbon monoxide, hydrocarbons, oxides of nitrogen (NOx) and particulates. Although exhaust emissions types and levels are largely dictated by fuel composition, combustion chamber conditions and exhaust after-treatment, the crankcase lubricant also plays a significant role.

The first regulations called for the use of exhaust system catalysts from 1/1/93 which in turn placed particular demands upon the lubricant, since catalysts would not tolerate certain of the additive elements historically used in lubricants. Phosphorus, for example, which is present in the commonly used anti-wear and anti-oxidant additive, zinc dialkyldithiophopshate (ZDDP), collects primarily at the catalyst face, with lesser amounts present over the remaining length of the catalyst, and adversely affects catalyst light-off performance. Reducing exposure of the catalyst to phosphorus can only be accomplished by reducing oil consumption and by reducing the phosphorus content in the lubricant. This in turn caused concern in terms of achieving the desired levels of component durability, friction reduction and extended drain intervals, since ZDDP is not readily replaceable. Additive technology is evolving to enable satisfactory lubricant performance even with reduced levels of phosphorus.

Reductions in NOx levels in diesel exhaust emissions can be achieved by retarding injection timing, although higher soot levels result placing an increased burden on the lubricant in accommodating increased soot contents without loss of performance. Soot accumulation in diesel engines in particular is a major problem, since small soot particles (20-30nm.) cause thickening of the oil, these primary particles then rapidly fusing together to form larger particles in the order of 0.2-0.3μ which then accelerate wear. However, the new Euro limits for diesel exhaust NOx emissions cannot be achieved by further retarding injection timing alone, hence the use of Exhaust Gas Recirculation (EGR). EGR dilutes the incoming air-fuel charge with non-combustible components, reducing peak flame temperature, which in turn reduces NOx generation. Even more benefit is achieved if the exhaust gases are cooled before recirculation, since better cylinder filling and more power result. In fact, the use of EGR is so effective in reducing NOx generation that injection timings can be advanced so that soot formation is reduced and economy improved. In such systems, the lubricant needs to tolerate the increased presence of water vapour and other combustion products, to avoid the possibility of emulsification. Lubricants tailored to the needs of EGR-equipped engines will be required when the new emission levels become mandatory, and work is well advanced in developing the new formulations.

Other design developments in diesel engines include the introduction of articulated pistons with steel crowns and high top rings, in addition to increased injection pressures and EGR.

In the UK, the government has now introduced a differential vehicle taxation system for new cars, based upon their CO^2 emission levels (grammes of CO^2 emitted per kilometre travelled)

	VED* Band 'A'	VED* Band 'B'	VED* Band 'C'	VED* Band 'D'
CO_2 g/km emissions	Up to 155	151 - 165	166 - 185	Over 185
Alternative Fuel Car	£90	£110	£130	£150
Petrol Car	£100	£120	£140	£155
Diesel Car	£110	£130	£150	£160
*VED = Vehicle Excise Duty				

Although current cost differential are relatively trivial, and would not be expected to unduly influence vehicle choice, the fact is now that the principal has been introduced one can confidently anticipate the differentials to increase when increasing pressures are brought to bear in order to further reduce emissions arising from motor vehicles. OEMs are now required to submit details of vehicle emissions in controlled test situations; details may be found on the website http://www.dvla.gov.uk/newved.htm.

Fuel sulphur levels have also been progressively reduced over the years, initially to reduce sulphur dioxide emissions but also now to maintain exhaust catalyst efficiency over prolonged periods. Most catalyst manufacturers consider that sulphur levels, certainly below 50 ppm, and preferably below 10 ppm, are necessary for de-NOx trap-type catalysts to work effectively. A programme of planned fuel sulphur level reductions was introduced some years ago, although many suppliers have anticipated future requirements, and ultra-low sulphur fuels are already widely available. In some ways, the introduction of low sulphur fuels, with consequent reduction in the form of acidic by-products of combustion, have made life somewhat easier for the lubricant, but sulphur levels in lubricants are likely to be the next target for further reductions in the quest to reduce emissions even further.

3. CUSTOMER SATISFACTION

Increasing drain intervals are being increasingly demanded by cost-conscious fleet operators, and they are also a useful marketing benefit for private owners. Other benefits include the conservation of oil resources, as well as reducing potential environmental hazards arising from incorrect waste oil disposal. OEMs such as Mercedes Benz, VW and BMW are predicting that today's intervals, averaging 15-20,000 km. will be extended to 30,000 km. or more by 2004. VW are also predicting a goal of 50,000 or a two year interval for passenger car diesel oils, and 30,000 km. for gasoline car oils. Some of the latest heavy commercial vehicles, e.g. Volvo and Mercedes Benz are offering 100,000km. between drain intervals. The latest ACEA (E5) specification aims to support

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these longer drain intervals without the need to use largely synthetic-based lubricants However, there are inevitable problems which are encountered when attempting to extend lubricant service life. Among these are engine durability concerns as anti-wear additives are depleted, loss of fuel economy performance; cold start performance due to oil thickening, deteriorating engine cleanliness with the formation of sludge; deposits due to depletion of the detergency additives, and an increase in engine wear leading to increased oil consumption, which will offset the environmental benefits of extended drain intervals. Accumulated contaminants include soot, unburnt fuel, metallic particles, acidic by-products of fuel and lubricant combustion, etc. Also, the more stringent the controls on emissions, the greater the potential for lubricant contamination.

Since lubricant life is not only a function of lubricant quality but also on vehicle usage pattern, use of an oil change monitoring system to detect end of life conditions is preferable to operating at fixed drain intervals. A number of basic systems are already available on certain vehicles, which monitor usage patterns including cold starts, high load operation, high oil temperatures and length of running time. These are likely to become more sophisticated over time, and will involve the assessment of oil degradation by measuring certain electrical properties. Lubricant life can also be extended by design factors such as increasing sump size, or by providing additional by-pass filtration systems, e.g. additional barrier filters, refiners and centrifugal systems. A number of claims for greatly extended lubricant life have been made for many of these 'add-on' systems, but their use is not universal, although the use of e.g. refiners is particularly beneficial in intermittent-use situations such as school buses where fuel dilution is a particular problem.

IMPLICATIONS FOR ENGINE OIL SPECIFICATION AND LICENSING SYSTEMS

The API system for engine oils has served the industry well over the latter part of the last century, particularly so after the early 1990s when the chemical additives industry, (originally the Chemical Manufacturers Association, CMA, now the American Chemistry Council, ACC) tightened up the engine sequence testing procedures. However, the status quo is unlikely to prevail for a number of reasons.

- With the increasing demands from the OEMs, the legislators and the consumers already highlighted above, coupled with the increasing variety of technologies available to the OEM, the lifetimes of each specification are becoming shorter. As a consequence, there is less time available for the developers, in particular the additive manufacturers, to recoup the enormous investments involved in developing new additive chemistries to meet increasingly stringent specification requirements.
- New formulations are taking too long to develop, and occasions have arisen when certain of the specified test equipment has become obsolete by the time that the new specification chemistries are complete.
- For some time, a number of OEMs no longer regard a standard API specification as being sufficiently comprehensive for their particular needs, and a number are attaching their own specific requirements in addition.
- The current situation has led to 'commoditisation' of engine oils, with little in the way of incentive for oil companies to develop new oils which not only meet but substantially exceed the basic specification requirement, which would obviously benefit the consumer. However, the additive companies have not benefited from this stagnation due to the over-short lifetimes already mentioned.

This situation has prompted a major re-think of the situation in the US, with its potential for impact on the European situation.

A proposal from the ACC is that the whole of the current processes and specifications, including the API 'S' and 'C' categories, the 'gasoline-fuelled' GF system, the new DHD system from the Engine Manufacturers Association, and the API 'doughnut' and ' starburst' trademarks, should be all discontinued, and be replaced with a new system relying completely on the OEMS working in conjunction with an additive manufacturer, to set and control limits for engine oils tailored to their own specific needs.

OEMs could than specify a lubricant by grade and manufacturer, as opposed to the current system which identifies suitable lubricants by means of a general product specification

This would ensure that individual OEMs would benefit from having a tailored lubricant specific for their needs, and enable fuel consumption and service intervals to be optimised to their own particular technology. To maintain these benefits, it would be necessary to ensure that the same lubricant was used for subsequent service fills, and this would be part of the normal warranty requirement during the warranted life of the vehicle.

However, environmental legislators may well require that the same lubricant to be used beyond the normal warranty period to safeguard the continued environmental benefits of low fuel consumption and reduced service intervals.

This proposal, whilst in its infancy, appears to be gathering momentum in the US; some senior figures in the lubricants industry have already commented that its adoption is not a question of 'if' but 'when'.

ACC is claiming that this new approach will also:

- Establish a marketplace, which is more easily understood by consumers.
- Encourage the development of higher-performance lubricants, which will be differentiated by price.
- Provide enhanced product choice for the consumer, although some of these advantages are being questioned by some.

Whilst such a proposal has merit in the US, with the big three OEMs equating coincidentally but conveniently to the big three additive manufacturers, the impact upon the rest of the world, in particular Europe, is less clear-cut. Although in Europe we have already witnessed a series of mergers of OEMs, and a globalisation of the auto industry, there are a greater variety of smaller-volume and specialist OEMs who would not have the resources to work with additive suppliers to develop their own lubricants.

However, we are already aware that the current European 'block exemptions' legislation may not be renewed, which may well also affect the current requirement to specify lubricants by specification rather than by brand. This could then open up the possibility of European manufacturers reverting to the practice of many years ago by specifying lubricants by brand rather than by specification, which could fit in nicely with the ACC proposals.

This issue is certain to be debated at length over the coming months, the BLF would welcome comments from members. Copies of the ACC proposals are available from the Secretariat.

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