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A Road Map for Engine Oils in India

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ABSTRACT

The Indian automotive industry is undergoing considerable and rapid change. The staged regional implementation of the current Bharat III (Euro III) emissions legislation and the proposed Bharat IV (Euro IV) standards in 2010 are driving these changes. These new emissions norms present new technical challenges and will add complexity to the industry in several sectors, including fuel refining, hardware and after-treatment manufacturing and lubricant supply.

In the refining sector, fuel quality and refinery capacity are well known issues that now are further compounded by quality and complexity issues associated with the widespread introduction of biofuels.

OEMs will address the new emissions regulations with new engine and exhaust aftertreatment strategies whilst the drivers to maintain and extend hardware and emissions control system durability still remain. Future issues for OEMs include the increasingly divergent lubricant performance needs of passenger car and heavy-duty applications driven by the advances in hardware technology in each application. There is also the possibility of future mandatory fuel economy targets, which may drive further complexity into the Indian engine lubricant market.

In order to provide the right oils for the various applications and to enable these new hardware technologies in this complex operating environment, oil marketers and additive manufacturers need to anticipate the performance and demands presented by these new market needs. This paper gives an overview of these challenges, drawing on experiences in the European and US markets, and discusses the impacts of these new challenges by providing a road map for engine oils in India.

KEYWORDS: Oil, Emissions, Air quality, Bharat, Fuel quality, Sulfur, Biofuel, Exhaust aftertreatment

INTRODUCTION

This paper examines the key factors driving change in the Indian automotive sector, and specifically how these factors relate to evolution in engine hardware, fuel quality and engine oil requirements. The overriding driver in India is air quality improvement through emissions reduction. This paper further examines how the planned changes in emissions regulations will influence fuel quality, engine technology and exhaust after-treatment selection to meet these emission reduction goals, and how this relates to evolution of the engine oil market in India. The various issues, challenges, compromises and possible solutions to achieve these goals are presented and discussed in terms of a road-map for engine oils in India.

Air quality improvement is driving rapid changes in the Indian automotive and related industries. The Bharat emissions limits are generally following the European norms with a staged application of advanced region-specific emissions limits for 11 selected metropolitan areas that have been defined as pollution hot-spots requiring special attention. The emission regulation implementation timeline is shown in Figure 1 below. All areas outside of the 11 defined regions lag by one Euro/Bharat level. For example the current limits are Bharat III for the 11 defined metropolitan areas, while the rest of India is at Euro/Bharat II level.

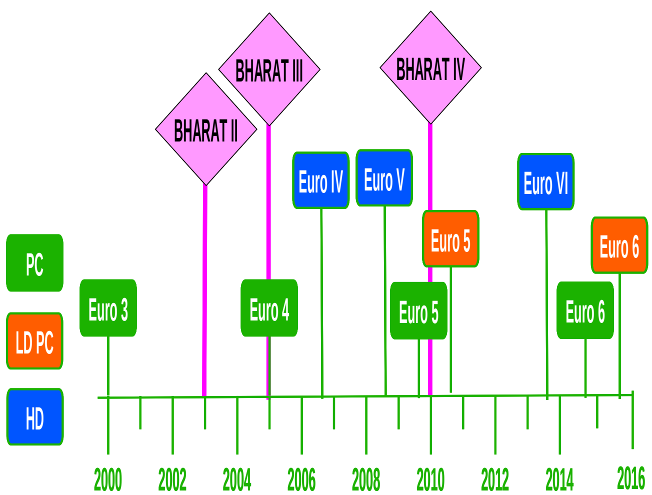
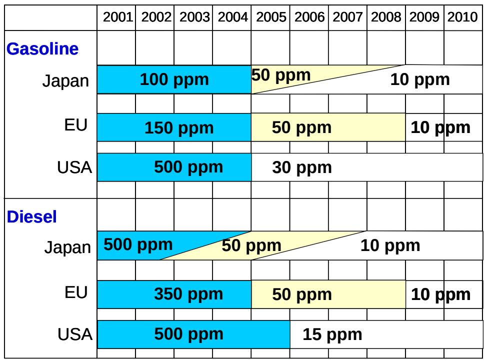


Figure 1. Euro and Bharat emission regulations implementation and fuel sulfur limits timelines



Data Source: Misono JCAP presentation. SAE Fuel & Lubes Toulouse, 2004

The reasons for the staged implementation of the Bharat emission limits are twofold. The primary reason is to address the pollution problems in the large cities such as Mumbai, Delhi, etc., where rapid implementation of the air quality improvements would provide most benefit. The second reason is that improvements in fuel quality are required to enable exhaust aftertreatment technologies to meet the new emissions requirements, particularly reductions in fuel sulfur content. Fuel sulfur has a direct impact on engine-out particulate emissions, which in turn increases the severity of diesel particulate filter blocking. It can also have a deleterious effect on NOx control technologies. The typical fuel quality levels for Japan, Europe and the US are also shown in Figure 1.

For the implementation of Euro IV in 2005, sulfur levels were reduced to <50ppm to enable and maintain durability of the aftertreatment hardware necessary to meet the new emissions limits. These increases in fuel quality required the refining industry to invest billions of dollars in recent years in hydro-treating units, catalyst technology and hydrogen plant to meet the demand for these new lower sulfur fuels. For India, the staged regional introduction of the Bharat emissions norms has allowed a staged introduction of lower sulfur fuels and investment in the new technology required to refine them. This has addressed the problem of managing refinery investment and the capacity restrictions that would preclude a full market upgrade. However, it has created the unusual situation where lower sulfur fuels are available within the 11 city regions, but when vehicles travel outside of the city they need to run on the higher sulfur fuel. With the introduction of Bharat IV in 2010, the general expectation is that average sulfur levels outside of the 11 metropolitan areas will be about 350ppm, so any new Bharat IV DPF-equipped vehicles will have to cope with the additional sulfate ash particulate blocking severity. There is additional impact on oil durability, particularly due to higher sulfur fuels generating more combustion acids that the oil additives need to neutralize. This will be addressed later in this paper.

There also are new fuel quality and severity issues related to the widespread introduction and penetration of biofuels in the Indian fuel market. Biofuels often have variable quality due to multiple feed-stocks, processing, sourcing points, etc. However, introduction of new standards has effectively started to regulate quality. Performance issues also exist particularly related to low biodiesel volatility leading to bio-component accumulation in vehicle sumps and excessive fuel dilution. Additionally, relatively low oxidative stability of the bio-component in the fuel dilution significantly impacts lubricant durability. Again, this has implications for oil durability in terms of neutralizing acids formed by the oxidation of the bio-component in the fuel dilution. There are also potential wear protection implications in situations where excessive fuel dilution can lead to a rapid lubricating oil viscosity drop. This is a particular concern for older vehicles running on older non-licensable specification oils, which in the absence of robust testing or performance modeling support, may not be as durable as when the specifications were licensable. Under these conditions and with these new market severities it becomes critical for the oil to remain robust. In some cases the existence of older OEM specifications may act as a performance guard against reduction in performance of non-licensable baseline specification oils.

The vehicle OEM's also face challenges implementing the new Bharat regulations. In particular, Bharat IV will introduce the wide-spread use of in-cylinder and exhaust aftertreatment technologies to control particulate and NOx emissions. As mentioned previously, having different fuel sulfur levels in the cities and the rest of India will mean that the selection of aftertreatment technology and the right oil to ensure lubricant and hardware durability will be critical. The impact of biofuels and other aftertreatment-specific changes in vehicle operation will need to be taken in account when defining future performance specs and oil drain intervals. Decisions also need to be made regarding the right oil for future passenger car applications. As passenger car and heavy-duty applications diverge in terms of severity and lubricant appetites (due to the use of different in-cylinder and exhaust aftertreatment emission control technology strategies used), it may be necessary to consider specially formulated passenger car lubricants for the Indian market rather than the logistically favorable heavy-duty lubricant cross fleet application, which so far is prevalent and successful. Another major driver probably will be the introduction of low viscosity fuel economy oils for passenger cars, already a common feature of European passenger car OEM specifications.

It is clear that the road to better air quality in India is littered with complexity and potential hazard. The aim of this paper is to examine some of these key issues in the context of the European market experience to demonstrate the critical need for the right oil for the application.

DISCUSSION

The issues highlighted in the introduction are discussed in greater detail below, with examples and industry analogies to the European and other world markets used to illustrate some of the issues that India will have to address in the near future. These issues are addressed individually, but the interplay between them is a major source of the complexity in the path to better air quality. The concluding section of this paper provides an overview of these key issues and a potential road-map for engine oils in India to ensure a successful transition to the clean air goals

EMISSIONS

The emissions regulation timeline in India is presented in Figure 1 and the general approach is discussed in the introduction to this paper. Focusing on the heavy-duty sector initially, the Bharat emissions norms are currently tracking the evolution of the European norms, which are presented in Table 1 below.

Emissions	Year	CO	HC	PM	NOx
Euro I	1992	4.5	1.1	0.612 for >85kW / 0.36 for	8
Euro II	1996/8	4.0	1.1	0.25 / 0.15	7
Euro III	2000	2.1	0.66	0.1	5
Euro IV	2005	1.5	0.46	0.02	3.5
Euro V	2008	1.5	0.46	0.02	2

Table 1.Basic summary of heavy-duty European emissions standards. (g/kW.hr)

The major implications for the Indian market will be that exhaust gas aftertreatment systems will need to be used to meet the new Bharat IV standards, particularly the use of oxidation catalysts, the use of exhaust gas recirculation (EGR) to control NOx, and the probable introduction of particulate filtration technology. In the European market, the general evolution of engine hardware to meet the Euro emissions norms and the aftertreatment options available are summarized in Figure 2 below.

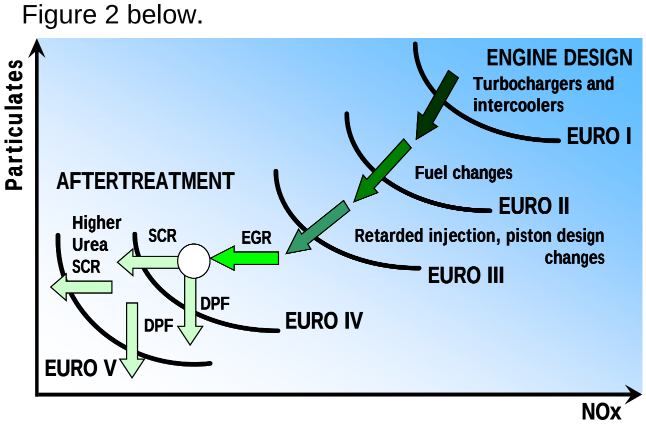


Figure 2.European hardware evolution for heavy-duty emission control: Pre-Euro → Euro V

For India, the selection of market-suitable aftertreatment systems for Bharat IV and beyond will be a critical part of OEM hardware developments, and these decisions must be made with the fuel quality sensitivity of these technologies in mind. For Bharat IV, the selection of oxidation catalysts and particulate filtration will need to be made according to the prevalent fuel sulfur level, which in 2010 is expected to be 50ppm for the metropolitan regions and 350ppm for the rest of India. The average fuel sulfur levels are much higher than the blanket 50ppm figure for Europe with the introduction of Euro IV in 2005, so special consideration must be given to the aftertreatment and lubricant technologies used. With the widespread introduction of diesel particulate filter (DPF) technology, one of the key enabling factors for DPF service life and ash-blocking durability is the availability of lower ash lubricants to reduce ash-blocking of the DPF. In turn, reducing fuel sulfur to <50ppm enabled the use of the lower ash lubricants in Europe

The low sulfur fuel used in Europe will not be available in India to allow use of lower ash lubricants; the higher fuel sulfur will likely result in a relatively higher detergent TBN requirement for Bharat IV compared to Euro IV. As a result, DPF technologies with higher ash tolerance than conventional wall-flow designs will be required to enable use of conventional higher ash lubricants, which in turn are required to provide the necessary lubricant durability in the presence of higher sulfur fuels. The use of lower ash oils is potentially possible; however, in the presence of higher sulfur fuels, drain intervals may need to be reduced significantly to compensate for the lower detergent TBN reserves

The implications of selecting higher ash tolerance DPF technology extend beyond the service life of the DPF unit. They also could significantly impact the costs to run a vehicle, both in terms of fuel economy (via reduced blocking and back-pressure build up) and reduced down-time by maintaining current drain intervals (by acting itself as an enabler for conventional higher ash lubricants to cope with the higher fuel sulfur levels). Data illustrating the effect of conventional DPF blocking is presented in Figure 3, where the relative difference in the rate of back-pressure increase through ash-blocking of the DPF can be seen clearly. In this European bus field trial, the lower ash ACEA E6 oil provided a much lower rate of back-pressure increase through DPF blocking. The resulting differential in back-pressure was related to ~1.5% fuel economy penalty for the higher ash lubricant, resulting in a vehicle fuel cost penalty of >€350/year

DURABILITY

Biofuels – a new destination?

While looking at fuel quality influences on the Indian market, it is important to address some of the fundamental changes occurring in the fuel supply chain

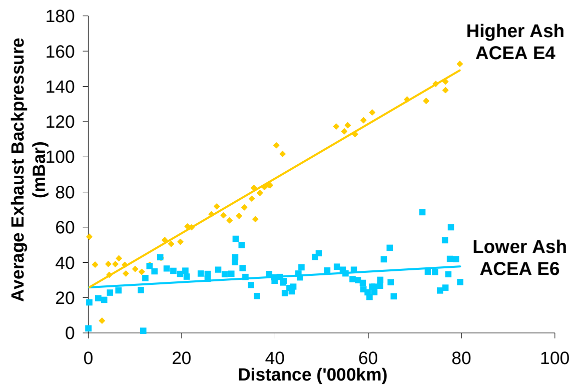


Figure 3.The effect of lubricant ash level on DPF blocking and resultant back-pressure build-up

The automotive and related sectors are acutely aware of the growing focus on renewable energy sources to ensure security of supply and to reduce CO_2 emissions produced by fossil fuels. The use of biofuels is a definite step toward achieving both objectives. Globally, the use of biologically derived fuels is rapidly increasing. The use of biofuels is predominantly led by legislation, but it is also supported by incentives such as reduced tax and agricultural subsidies on biofuel feedstock crops. Projections are that biodiesel production will increase from just over 10MM MT per year in 2006 to over 60MM MT per year in 2010, with further growth projected beyond that. In Europe the EU Transport Policy is targeting replacement of 20% of conventional on-road fuels with substitute fuels by 2020. This is supported by the European Biofuels directive [1] which is targeting 5.75% biofuel use in the European fuel market for 2010 and 10% use by 2020.

The quality variability of biofuel has been an issue in the recent past and is largely a function of the large number of feed-stocks, processes and supply points. In Europe, biodiesel quality standards such as BQ9000 [2] and EN14214 [3] have greatly improved quality and consistency, and the introduction of similar regional standards around the world are becoming more common. An example is Indian Standard 15607:2005 [4] for biodiesel to be used as a diesel fuel blend stock. However, there is no global harmonized standard for biofuels. The main issue with bio-diesel is its reduced volatility compared to mineral diesel, as shown in Figure 4.

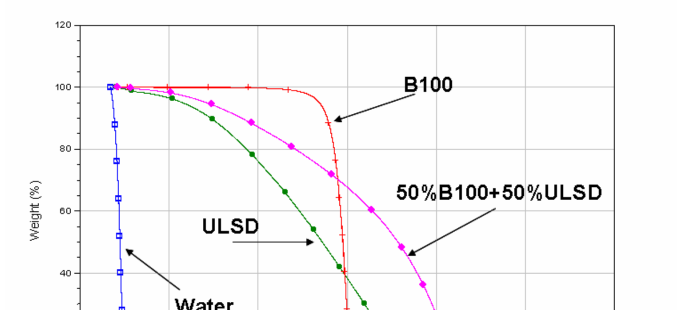


Figure 4.Thermo-gravimetric comparison of EN:590 mineral diesel versus bio-diesel and a 1:1 blend

This can lead to the bio-component of the fuel dilution concentrating in the sump, a problem significantly exacerbated in hardware using fuel post-injection for DPF regeneration. In such systems excess fuel injected into the cylinder to raise exhaust gas temperatures sufficiently to initiate the DPF regeneration process results in excess fuel coating the cylinder liner walls, significantly increasing overall fuel dilution effects. In passenger car applications run on 5% biodiesel blends, total fuel dilution levels of >10% have been commonly observed with bio-component levels comprising >20% of the fuel dilution through the lower volatility accumulation effect described. It should also be noted that even in the absence of post-injection, significant fuel dilution has been observed, including in some heavy-duty truck applications, as shown in Figure 5.

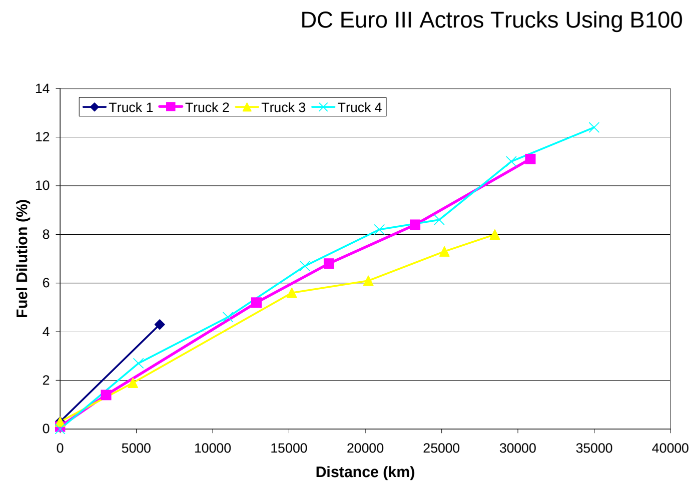


Figure 5.European truck biodiesel field trial fuel dilution data

Fuel dilution raises other issues regarding engine oil durability. Biodiesel is well known to have relatively poor oxidative and thermal stability compared to mineral diesel, which has been investigated in detail below. The results of recent studies on the effect of biodiesel versus mineral oil fuel dilution on oxidation stability, and consequently on bulk lubricant durability are presented below in Figure 6 and Table 2.

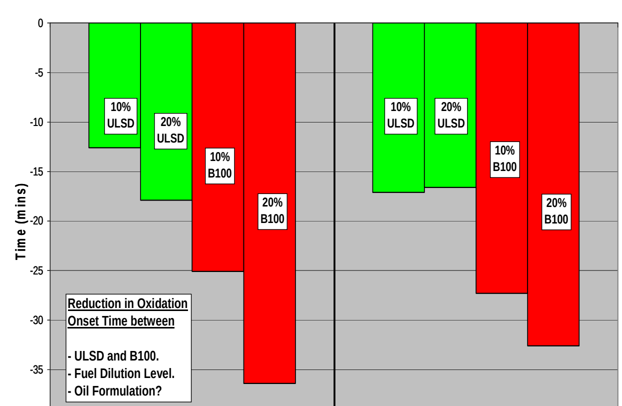


Figure 6.Comparison of biodiesel and mineral diesel dilution effects on lubricant durability using PDSC

It is observed initially in the pressurized differential scanning calorimeter (PDSC) studies (Figure 6), that both mineral and biodiesel fuel dilution significantly reduces oxidative stability versus non-fuel diluted fresh oils. However the biodiesel has significantly higher oxidative severity than the mineral diesel. When it is considered that the biodiesel is likely to accumulate at far higher levels than the mineral diesel due to its relatively higher volatility, it is clearly a cause for concern. On a simplistic level, higher levels of fuel dilution can result in a rapid viscosity loss in the lubricant, which could cause engine wear problems. This emphasizes the need to use highly durable lubricants with robust anti-wear performance in markets where biodiesel usage will become prevalent. This may be an issue particularly in some centrally-fuelled off-road applications using 100% biodiesel instead of conventional on-road bio/mineral diesel blends.

Several European and North American OEMs have issued guidelines for the use of biodiesel blends in their hardware. In most cases, the use of up to B05 is accepted with no change in service interval recommendations. However, for higher than B05, there are a range of recommendations for reduced drain intervals and absolute caps on the level of biodiesel that OEMs will warrant. This confirms that the concerns are real and that the issues associated with biodiesel span the range of commercial hardware technologies and applications in the European and North American markets.

The bulk oxidation testing (Table 2) was completed using a Lubrizol proprietary in-house bench test method designed to simulate long-duration thermal and oxidation durability. Fuel dilution is observed to be deleterious to lubricant durability; the biodiesel was much more severe than the mineral diesel. For both fuels, increases in Total Acid Number (TAN) and viscosity (through oxidative thickening) were worse with higher levels of fuel dilution. Again, given the accumulating tendencies of the bio-component, this gives further reason for concern.

	Test	Fuel Dilution	Oil A ULSD	Oil A B100	Oil B ULSD	Oil B B100
Change Compared to Fresh Oil	Change in TAN (mgKOH/g)	0%	0.6	0.6	2.0	2.0
		10%	3.4	5.6	2.9	4.4
		20%	4.1	9.2	3.1	6.9
	Change in KV40 (cSt)	0%	-6.3	-6.3	-1.8	-1.8
		10%	8.9	21.6	18.3	16.6
		20%	21.2	124.7	30.2	50.0
	Change in KV100 (cSt)	0%	-1.2	-1.1	-0.5	-0.5
		10%	0.5	2.2	1.5	1.5
		20%	2.3	19.8	3.3	6.3

Table 2. Bulk oxidation data comparing biodiesel and mineral diesel effects on lubricant durability

The TAN increase is caused by the formation of acidic byproducts from the oxidation of the lubricant and fuel components. The increase in severity in the case of the biodiesel is clearly a function of its relatively low thermal and oxidative stability versus mineral diesel. This has been studied and is presented in Figure 7.

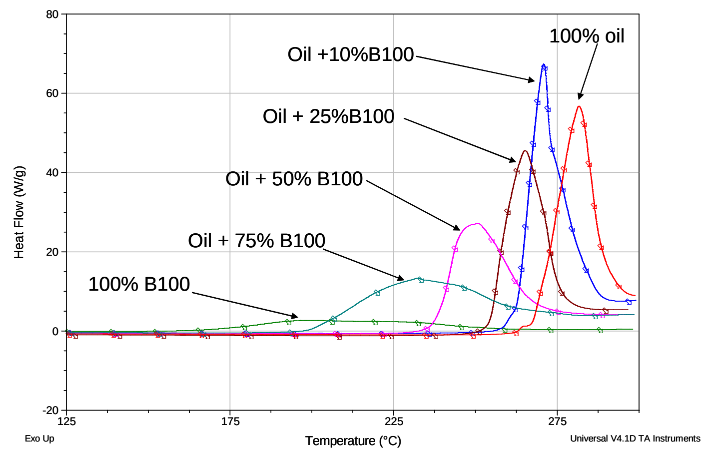


Figure 7.PDSC oxidation onset test results for increasing bio-diesel concentration in lubricating oil

TBN retention – a dead-end performance measure?

Following the subject of elevated TAN increase severity due to biodiesel fuel dilution, it should be noted that Total Base Number (TBN) measurement cannot be relied upon as the sole measure of TBN reserve for determining useful life of an engine oil. There are two methods commonly used for TBN determination: ASTM D2896 (perchloric acid method - for fresh oils), and ASTM D4739 (hydrochloric acid method - field trial and engine test oil samples). Each of these test methods has different sensitivities to mineral acids and neither is sensitive to organic acids (based on testing using acetic acid). Given the demonstrated increase in TAN build up in the case of biodiesel fuel dilution, it is clear that TBN measurement alone is not sufficient to establish the true performance reserves of a lubricant, and that in markets where biofuel use is prevalent, use of durable lubricants is imperative.

In recent years, the reduction in fuel sulfur levels has reduced the focus on TBN. The argument has been that lower sulfur fuels result in less combustion acid formation, therefore there is less need for the lubricant to neutralize acids throughout its service life. The studies presented here demonstrate that there still needs to be a clear focus on TBN management in the lubricants of today because the need for effective acid neutralization will be exacerbated by the introduction of biodiesel. It is also important not to trivialize the TBN measurement as just a base reserve in the lubricant for acid neutralization. The detergent, dispersant and antioxidant derived TBN not only reflect on the oils' ability to neutralize acids, but also on the formulation robustness in other performance areas, such as piston cleanliness and oxidative stability performance; both of which are key issues in biodiesel introduction.

Specification erosion – a dangerous path

One of the key challenges the lubricant market faces is that in certain parts of the world there is a significant presence of and need for products based on obsolete API categories. This presents a challenge to demonstrate suitably robust performance. One of the key safety measures to ensure robust performance has been combining baseline lubricant performance specifications with OEM performance claims (which require performance testing and/or validated read-across). Given the clear lubricant durability issues associated with the biodiesel use, maintenance of these OEM performance claim requirements alongside non-licensable categories should effectively underpin the performance of these lower quality lubricants, thus ensuring durability. The issue of performance erosion also extends beyond TBN to wear protection.

For example, formulated oils are available in the Asian market at the non-licensable API-SF [5] level, which contain as little as 500mg.kg^{-1} phosphorus. Whilst these formulations may be supported against a baseline specification, engine testing data in a Sequence VE [6] test comparing 500mg.kg^{-1} phosphorus with a more conventional and durable 800mg.kg^{-1} phosphorus formulation demonstrates that there is a large performance gap in real-world wear protection between these two formulations, as illustrated in Figure 8 below. The compromised durability of the formulation containing lower phosphorus-based anti-wear chemistry is very significant. The higher durability formulation has a 200% increase in wear onset time compared to the lower durability formulation.

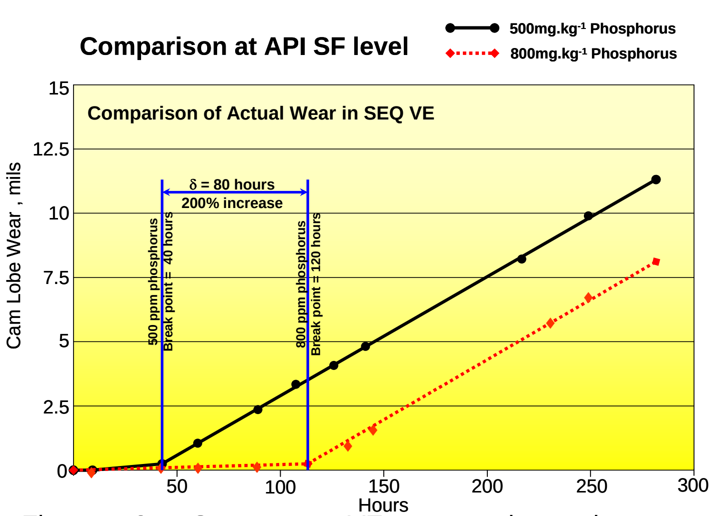


Figure 8. Sequence VE comparison between commercial API-SF formulations at 500 and 800mg.kg^{-1} P.

As well as maintaining durability in the lower performance tiers, which is a key industry responsibility, it is expected that the other major focus and growth area will be at the opposite end of the performance spectrum. At the top end of the performance tiers, increased vehicle sophistication is expected to increase workshop servicing compared to the current market, which in turn will increase the use of high quality lubricants with full OEM credentials.

Fuel Economy – a sign-post for the future

Wear protection durability is relevant to one of the most fundamental changes in future lubricant requirements; the need to provide fuel economy. The drive for fuel economy is dominated by the desire to reduce CO_2 emissions. Already, automotive OEM representative bodies have voluntarily committed to reduce CO_2 emissions in the EU, and it is highly likely that CO_2 could be adopted as a regulated pollutant in future EU legislation. It also is likely that fuel economy will soon become a key global lubricant performance parameter for all automotive applications.

There are two key lubricant technology levers to enable fuel economy benefits: use of friction modifier chemistries and of lower viscosity grades. Limiting the latter is wear-protection durability. In critical applications with lower viscosity oils, the durability of anti-wear additives will become increasingly important, especially given the possible reduction in viscosity associated with biodiesel-related fuel dilution. Figure 9 shows the effect of fuel dilution on High Temperature High Shear viscosity (HTHS).

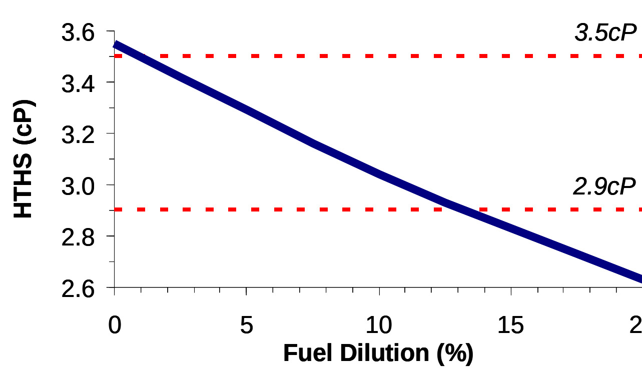


Figure 9. Change in 5W-30 passenger car engine oil HTHS with fuel dilution

This viscosity loss will potentially have significant impact on wear protection, emphasizing again that selection of robust lubricant technology is necessary to ensure durability of performance with increasing application severity.

Passenger car versus heavy-duty – is there a junction ahead?

The final issue discussed in this paper is a possible divergence in severity between passenger car and heavy-duty truck application lubricant requirements. In India it is commonplace to use heavy-duty lubricant formulations in passenger car applications, which clearly has clear logistical advantages over separate lubricants for each application. However, as we see the ever-increasing power densities in passenger car applications giving rise to higher cylinder temperatures, coupled with the potential requirement to use lower viscosity oils for fuel economy, it is clear that lubrication needs and component appetites will differ. The impact of biodiesel on fuel dilution leading to possible viscosity related wear and oxidative stability concerns, coupled with higher piston temperatures will likely lead to the requirement for higher piston cleanliness and highly durable anti-wear / friction modifier systems to meet performance targets while still maintaining lubricant durability

In terms of lubricant thermal durability and piston cleanliness performance requirements, the severity difference between passenger car diesel and heavy-duty diesel is quite significant, as illustrated clearly by comparing two of the key ACEA passenger car and diesel specification tests, the CEC L-78-99 VWDI (or TDi) test and the CEC L-52-97 (OM441LA). Comparable piston temperature measurements show temperature differentials of up to ~90ºC accounting for the higher piston cleanliness severity of the passenger car application.

This severity differential may be further increased by the introduction of biodiesel into the marketplace. In recent Lubrizol proprietary testing in a modern 2L diesel engine comparing mineral diesel fuel with a B10 fuel, fuel dilution related reductions in piston merit in have been observed to be significantly greater with biodiesel present when fuel dilution is relatively high. This is a reflection of the relatively low oxidative stability of the biodiesel fuel component. Given the higher piston temperatures in passenger car applications, there may be a need to enhance the high-temperature piston cleanliness performance of passenger car engine oils, both to address absolute increases in application severity versus heavy-duty and to address the possible severity increase due to the introduction of biodiesel.

CONCLUSION

This paper has attempted to address some of the key issues facing the automotive and related industries on the road to improving air quality in India. The destination has been set within the Bharat emissions specifications, and the challenge is to navigate through the complexities of the technical and commercial landmarks to this goal.

Some of the route has been partially paved by European experiences, in defining hardware strategies and exhaust aftertreatment technologies. However, some roadblocks, such as availability of low-sulfur fuel will require following a slightly different path. Several of the possible hazards ahead related to introducing biodiesel are new to the global industry. Care will need to be taken to negotiate this uncharted territory. The key issues of fuel dilution and the impact of reduced oxidative stability on lubricant performance and durability, and the additional contribution to TAN increase require that we take a cautious approach to lubricant durability to ensure that we stay safely on the right road. At the same time, we need to guard against tempting short-cuts, which may compromise performance with less durable specifications and inappropriate measures of lubricant durability, at a time when the application severity is increasing.

Finally, we need to keep our eyes on the road where we will see new performance destinations, such as fuel economy specifications, and possibly junctions where the passenger car and heavy-duty roads may split There may be several possible routes to the destination of improved air quality, however there is a clear need to maintain lubricant durability by using the right oil for the right application to ensure a safe and smooth journey.

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