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Why Base Number (BN) alone is not the answer when formulating cylinder oils for 0.5% sulphur fuels

The decision by the International Maritime Organization (IMO) to reduce the global fuel sulphur cap to 0.5% from 1st January 2020 is anticipated to have significant health and environmental benefits. However, with it come many challenges throughout the supply chain, including the need for higher-performance cylinder oils.

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Introduction

With over 90% of the world's trade being carried by sea, the importance of maritime transport cannot be overstated. The main type of marine fuel used for ships is heavy fuel oil (HFO), which is derived as a residue from crude oil distillation. As crude oil contains sulphur, following combustion in the engine, harmful sulphur oxides (SOx) emissions are emitted into the atmosphere.

The ongoing drive to reduce SOx emissions from ships is intended to reduce air pollution and create a cleaner environment, particularly for populations living close to ports and coasts. It is known that SOx can lead to acid rain which is harmful to forests, crops and aquatic species as well as increasing acidification in oceans around the world.

Likewise it is known that SOx is harmful to human health causing lung disease and respiratory symptoms. A study submitted by Finland to the IMO's Marine Environment Protection Committee (MEPC) in 2016, estimated that delaying a reduction in the SOx limit for ships from 2020 to 2025 would contribute to more than 570,000 additional premature deaths worldwide. Therefore, the decision to reduce the global fuel sulphur cap from 3.5% w/w (weight by weight) to 0.5% w/w from the start of 2020 is well founded and continues the IMO's progressive tightening of sulphur limits.

The introduction of a fuel sulphur cap below 3.5% is not new. While the reduction from 3.5% to 0.5% will apply globally to ships operating outside of designated emission control areas (ECAs), there is already an even stricter 0.10% sulphur limit in effect in emission control areas, having been reduced from 1.00% in January 2015 and covering: the Baltic Sea area; the North Sea area; the North American area (designated coastal areas off the United States and Canada); and the United States Caribbean Sea area (around Puerto Rico and the United States Virgin Islands).

Despite the industry having a reduced sulphur limit below 3.5% across selective geographical areas, the IMO's decision to reduce the global fuel sulphur cap has prompted much debate in the industry around the pathways to compliance. In addition, the consultant's report to IMO indicates that ≤0.5% sulphur fuels can be produced via a range of manufacturing and blending processes. Consequently, much of the discussion has centred on fuel availability, fuel variability and alternative compliance options like exhaust gas cleaning systems.

To meet the fuel demand after 2020 the majority of ≤0.5% sulphur fuels are expected to be produced via blends. Concerns have arisen in the industry about the variation in constituents of these blends and the effects they could have on stability, compatibility and combustibility. Lubrizol's concern as a lubricant additive manufacturer is the subsequent impact on combustion zone deposit formation. High performing lubricants are required to prevent excessive deposits forming which might impact engine efficiency and durability.

For two stroke marine diesel engine designers, additive and lubricant companies, discussions are related to what performance characteristics will be required for cylinder oils in a ≤0.5% sulphur fuel future. Operating at the interface between the fuel and the engine, the oil needs to be more than purely a lubricating fluid.

Today, access to fuels with a sulphur content of >0.1% and <0.5%, now termed very low sulphur fuel oils or VLSFOs, is limited to only a very few regions of the world; the most widespread supply being in China. Lubrizol has closely examined some of those fuels to understand their characteristics, their effects on engine deposits and more critically, how cylinder oils perform.

The results of this fuel and lubricant testing are discussed below and demonstrate how functional additives can effectively reduce the impact of fuel variability, with improved performance in the area of engine deposit control - aspects which contribute to improved engine durability. This goes beyond conventional cylinder oil formulating and demonstrates 'BN' (Base Number) alone is not the answer for these 0.5% sulphur fuels.

Fuels study

Shortly after the implementation date for the sulphur cap reduction was confirmed, concerns about the quality of 2020 compliant fuels began to be voiced. These concerns focussed on compatibility, stability, combustion characteristics, viscosity and pour points. The purpose of undertaking a fuels study was to try to validate the concerns and understand the implications they could place on lubricant performance requirements.

Without access to samples of very low sulphur fuel oils (VLSFOs) currently under development, commercially available 0.5% w/w sulphur fuels from China have been supplemented with a range of in-house laboratory blended VLSFOs. These laboratory blends have been derived from globally sourced high sulphur fuel oils (HSFOs) and the appropriate amount of distillate to achieve 0.5% w/w sulphur content. In total 5 commercially available VLSFOs and 5 laboratory blended VLSFOs were assessed.

Compatibility concerns relate to the co-mingling of incompatible bunkers on board vessels and can be managed through tank segregation until compatibility can be confirmed through testing. Stability refers to each individual fuel oil being a stable product. A contributing factor underlying both issues is asphaltene stability. Asphaltenes are present in all crude petroleum residues but vary in content and characteristics depending on the origin of the crude oil. Asphaltenes are high molecular weight polar molecules, predominantly aromatic in structure. Asphaltenes are sensitive to changes in the aromaticity of the total fuel matrix which changes on blending. Combining with a paraffinic refinery stream such as a low sulphur distillate to reach 0.5% w/w sulphur fuel would therefore increase the risk of the final blend being unstable. This instability could impact other characteristics of the fuel such as combustibility and the deposit forming tendency. The composition of fuel can be characterised by determining the quantity of Saturate, Aromatic, Resin and Asphaltene fractions (SARA). These fractions are each associated with asphaltene stability and thus this technique could be useful in identifying fuels with the potential for stability issues.

The stability of the commercial sourced VLSFOs was probed further using a proprietary bench test that gives a quantitative assessment of stability. The three most unstable commercial VLSFOs were then tested with two additives: Additive 1 is a detergent known to be effective in deposit control and asphaltene stabilization; Additive 2 is a Lubrizol novel dispersant known to be effective in deposit and varnish control and asphaltene stabilisation. Figure 1 shows the novel dispersant was the most effective in stabilising the fuel so it should show good dispersancy of deposits in the combustion zone.

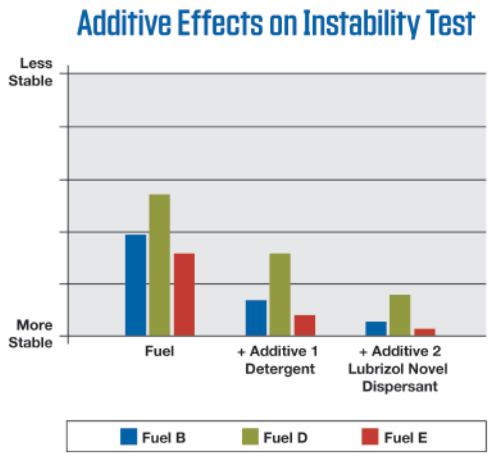

Figure 1: *Lubrizol novel dispersant significantly increased fuel stabilization in each of the three most unstable VLSFOs tested.*

Following this stage, a number of marine diesel cylinder lubricants (MDCLs) were tested in a 2-stroke engine to evaluate performance in terms of deposit control and corrosion protection, the results are discussed below.

Engine testing with Very Low Sulphur Fuel Oil (VLSFO)

Base number (BN), a measure of acid neutralisation capacity, has become a defining performance characteristic for MDCLs, forming the basis of OEM lubricant selection guidelines in relation to the sulphur content of the fuel being used. During combustion the sulphur undergoes oxidation reactions which leads to the formation of sulphuric acid (H_2SO_4). Where temperatures in the combustion space drop below the acid dew point condensation occurs, which drives corrosive wear of critical engine parts such as the cylinder liner. Corrosive wear has been shown to be effectively controlled by selecting a MDCL with sufficient acid neutralisation capacity.

When operating on high sulphur HFO, which currently averages globally around 2.7% w/w sulphur, the use of 70 BN and above MDCLs is recommended. The move to <0.5% sulphur fuels will reduce the total amount of acid that can be generated and thus the potential for corrosive wear. Therefore, a lower BN lubricant is more appropriate for operating on low sulphur fuel as excessive base can accumulate as hard abrasive deposits on piston crown lands with the potential to cause bore polishing or scuffing. 40 BN lubricants emerged as the preferred choice when operating on up to 1.5% w/w sulphur fuel and since 2015 when the fuel sulphur content in emission control areas was capped at 0.1% w/w, 15-25 BN lubricants have been utilised with satisfactory protection of engine hardware from corrosion.

Additives used to deliver base in lubricants are over-based detergents that also help to keep the engine clean of deposits. One of the benefits of 70 BN and higher lubricants is they inherently contain a substantial amount of detergent soap and these generally cope very well with the variation in HSFOs today in terms of deposit control.

The type of detergents selected (e.g. sulphonates or phenates) also impacts this aspect of performance. Reducing the BN by simply adjusting the over-based detergents without rebalancing the formulation with additional deposit control additives will severely affect the lubricant's ability to keep the engine clean, even without the added variability anticipated with fuels post 2020.

Variability is inevitable when considering the range of blend stocks and refining processes that could be used to produce <0.5% sulphur fuels in order to meet demand. This variability will present a variety of challenges to ship operators from determining compatibility of different batches, to engine deposit formation where having a lubricant with the right performance characteristics will be key.

In order to determine the appropriate BN and deposit control requirements of MDCLs for use with <0.5% sulphur fuels, Lubrizol formulated a series of 25 BN and 40 BN MDCLs and tested these with commercially sourced <0.5% sulphur fuels in a stationary two stroke marine diesel engine.

Measuring residual BN in scrape down samples every 25 hours during the engine test is used to indicate if the BN of the lubricant is delivering sufficient protection from corrosive wear. To maintain satisfactory corrosion protection, the residual BN of the scrape down oil should be around 15 BN according to OEM guidance. The average residual BN for the 25 BN MDCLs across all tests was 12.5 BN compared to an average of 24.2 BN for the 40 BN MDCLs, as shown in Figure 2.

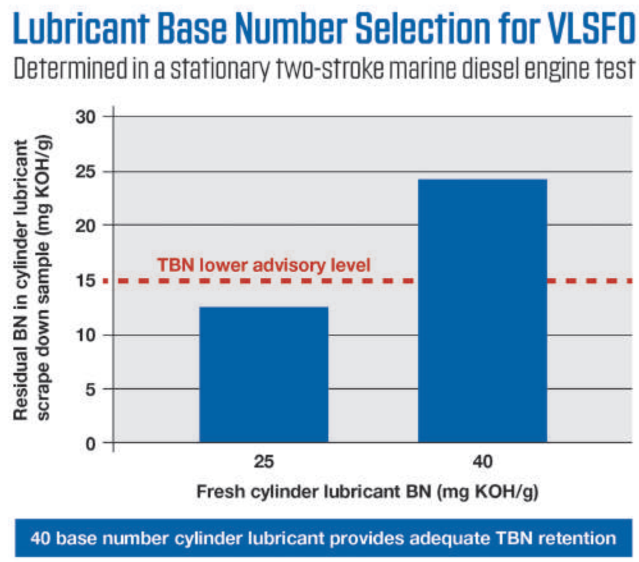

Figure 2: *Lubrizol testing concludes that 40 BN is more appropriate than 25 BN cylinder lubricant for VLSFOs.*

Therefore, Lubrizol concluded that 40 BN was the more appropriate BN for <0.5% sulphur fuels as it provides sufficient base reserve to meet OEM guidance with some flexibility for more corrosive engine types and operating conditions, than those experienced in the test engine.

With respect to engine cleanliness, detergents are not the only additives in the formulators tool kit; dispersants are very good at piston cleanliness and have been utilised in heavy duty diesel engines, for example, for many years, but are not commonplace in marine cylinder oils for deposit control.

Dispersants were selected for testing based on known performance benefits they deliver in their existing applications such as deposit control, varnish control and asphaltene handling.

These performance benefits are aligned with the additional performance challenges that <0.5%sulphur fuels are expected to pose to MDCLs compared to current HFOs as identified by Lubrizol's characterisation of a number of <0.5% sulphur fuels.

After screening the performance of a number of dispersants in marine bench tests, two were selected for further evaluation in the engine test. These were: a Lubrizol advanced dispersant known to be effective at addressing piston groove deposits and varnish; the Lubrizol novel dispersant that showed improved stabilisation of the commercial VLSFOs in Figure 1.

The Lubrizol advanced dispersant was used to formulate a 25 BN MDCL for comparison with a conventionally formulated 25 BN MDCL. The 25 BN MDCL with advanced dispersant had superior piston cleanliness with lower deposit formation in the piston ring grooves and on the piston lands.

A similar approach was taken for the 40 BN MDCLs. The performance of a conventionally formulated 40 BN MDCL was compared to a 40 BN MDCL that incorporated the novel dispersant. The 40 BN MDCL with the novel dispersant showed improved piston deposit control and piston land cleanliness.

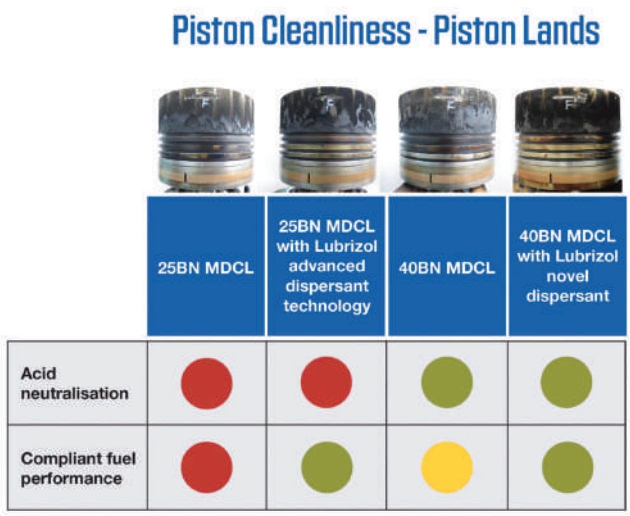

Figure 3: *Lubrizol's engine testing demonstrates a 40 BN MDCL with Lubrizol novel dispersant provides the required level of piston cleanliness performance in a 0.5% sulphur fuel.*

The results are summarised in Figure 3. Additionally, the results show the 25 BN MDCL with advanced dispersant showed improved performance over the conventionally formulated 40 BN MDCL. This demonstrates performance can be delivered independently of BN and illustrates why it is not sufficient to only consider the lubricant base number as the defining performance characteristic.

Conclusions

The testing conducted by Lubrizol demonstrated that 40 BN MDCLs previously developed for use with fuels up to 1.5% sulphur fuel may not provide the required performance, depending on operating conditions, when used in vessels burning VLSFOs.

It also demonstrated the effectiveness of dispersants to bring additional performance in the area of piston cleanliness compared to conventionally formulated MDCLs when using 0.5% sulphur fuel.

Lubrizol believes that the preferred and optimal lubricant solution for use with VLSFOs is a 40 BN MDCL specifically designed and formulated with robust deposit handling performance to address the expected fuel variability challenges and that has been validated with and approved for use with VLSFOs.

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