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CIMAC Guideline

Future Fuel Scenarios and their impact on Lubrication

By CIMAC WG 8 ‘Marine Lubricants’

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Content

Introduction

The purpose of this paper is to consider the various types of fuel, and combinations of fuels, that may be used by marine vessels through to 2025, and then to discuss the potential impacts that these fuel types may have upon engine lubrication. The paper also considers any mitigating factors that can assist in the safe and efficient use of such fuels.

The paper does not provide specific guidance on lubricant selection and use, but is intended to highlight potential problem areas, advise what symptoms to look out for, act as an "awareness raiser" for future fuel use and give clues as to potential impacts on engine lubrication.

Section 1 discusses the main generic fuel types individually, where they are considered as the most predominant fuel type. Section 2 looks at scenarios where the generic fuel types are used in various combinations. Further, the paper evaluates the potential combinations, firstly to rule out the unlikely combinations, and then to determine which are the most difficult combinations for industry to deal with from a lubrication point of view. As the marine two stroke sector will be exposed the greatest set of unknowns' then Section 3 provides some basic guidelines for inspection and monitoring practices that could be deployed.

The impacts on lubrication caused by future fuel quality as discussed in this document should be considered as general guidelines. In the first instance, instructions as specified by engine manufacturers should be followed.

1 Generic Fuel Categories

1.1 Fuels expected to contain residual components, meet IMO requirements of 2020/2025 and potentially ECA requirements of 2015 of <0.1% sulphur

<table>
<tr><td rowspan="3"><u>Fuel</u>
• < 0.50% sulphur
• A different category of fuel used across the industry of so far unknown quality
• Will likely become the dominant fuel type post 2020/2025 and will be legislated for use in EU waters from 2020.
• Can include fuel previously known as DMC (ISO8217:2005)
• Unlikely that refineries will desulphurise HFO</td><td><u>Lube</u>
• Impact on lubrication is so far unknown, but should become simplified due to a narrower fuel specification
• Correct level of detergency to deal with HFO components
• Need for moderate asphaltene handling</td></tr>
<tr><td><u>Two stroke applications</u>
• Based on current commercial products, will have medium BN of around 40 or below
• No impact on 2 stroke system oil</td></tr>
<tr><td><u>4 stroke applications</u>
• Based on current commercial products, will be 12 – 30 BN</td></tr>
</table>

This type of fuel can come in three potential versions:

1.1.1 Low sulphur HFO:

Usually sourced from local low sulphur crudes. Sulphur typically 0.30 – 0.80%. South American sourced Low sulphur HFO has been used for many years, but typically this has been in the form of discrete bunker supplies to ships that have called at a South American port and then sailed on elsewhere.

1.1.2 True desulphurised

Defined as when a refinery invests in desulphurising equipment specifically to reduce HFO sulphur to meet legislation limits. In practice, desulphurised HFO is unlikely to be produced.

1.1.3 Distillate/HFO blend (DMC/RMA 10)

This is seen as the most likely fuel type and will be the dominant fuel enabling the enforcement of the 2020/25 IMO legislation. It is assumed that this fuel will be a blend of middle distillate and HFO. The two types of fuel will be blended to bring the combined sulphur level as close to the 0.50% S limit as possible. This fuel may be inherently unstable which may lead to handling issues prior to injection in to the engine. Potential Total Sediment (TSP) can be carried out as part of routine testing as advised in the ISO 8217 specification (1). Consideration is also being given to an Accelerated Total Sediment test (TSA) and may be adopted in future. Fuel instability potentially gives problems with centrifuging and filtration of the fuel. In addition, the fuel may be blended from various refinery sources with components of unknown combustion qualities. However, it is considered that the quality of this fuel type may be more tightly controlled by revised fuel specifications such as amendments to ISO 8217.

Impacts on Lubrication:

To date there is very little experience or data gathered where this type of fuel has been in use for extended periods. The fuel will contain some asphaltenes and lube formulations must be able to deal with this contaminant with respect to engine component cleanliness. Unstable fuel may lead to combustion difficulties, the residues of which will need to be handled and tolerated by the lube oil.

Two stroke specific

It may be feasible that the current market 40 BN cylinder oils can be used with this fuel type in the absence of any developments of cylinder oil with differing properties and BN levels. It should also be noted that oils of BN's >40 have been used successfully in engines operating permanently in ECA regions however these have been very few in number and have likely received extra care with regard to monitoring and control of feed rates. As knowledge and experience of new fuels evolves, oil companies will work to develop new formulations of cylinder lubricants appropriate to the fuel and its application. With such lubricants using for example chemistries based on ashless components, the alkalinity reserve could be set differently, considering not only the sulphur content of the fuel used but also the engine characteristics, emission control and energy saving systems, and the operating conditions. It remains to be seen whether the current practice of slow steaming and its accompanying problems of cold corrosion will continue to affect engines burning this fuel type into the future, but this aspect may impact the choice of appropriate BN.

Four stroke specific

The lubricant approach for these engines will not be significantly different from the lubricants used today with fuels with an average sulphur content of about 2.5%. Although 0.50% (5000 ppm) sulphur is lower than the sulphur level present in the majority of residual fuels currently used, it is still a significant quantity and sufficient BN is required in the lube oil to neutralise the acidic combustion by-products. It is likely that the content of residual components (like asphaltenes) will in most cases be lower than in today's heavy fuel oils, however a good level of asphaltene dispersancy will still be required. Current commercial products are able to fulfill the requirements of the lubricant in the above scenario, however, a shift towards lower BN (e. g. 12-40 instead of 30-40) and for a move away from very high BN (like 50 or 55) will result.

1.2 Distillate

Fuel	Lube
<u>Fuel</u> • < 0.50% sulphur (middle distillate) • No residual components (no asphaltene)	<u>Lube</u> • Asphaltene handling not needed • Potential for liner lacquering
	<u>Two Stroke Applications</u> • Cylinder oil <= 40 BN • 2 stroke system oil no impact
	<u>4 Stroke Applications</u> • Existing recommendations stand

This fuel is currently classified as DMA, DMZ or ULSD. This fuel is set to predominate in ECA regions from 1st January 2015 at <0.10% S. ULSD may contain significant quantities of biofuel as prescribed for local inland markets. Currently ‘B7’ – 7% bio content – is typical in Europe. ISO 8217 international standard currently limits the FAME content to a “*de minimis*” level. CIMAC fuels working group have published a paper on this aspect (2).

<u>Two Stroke Specific</u>

This is the fuel that is likely to cause greatest concern with 2 stroke low speed engines. To date there is limited experience with respect to modern engines burning this type of fuel. In the limited applications to date, such as test beds, 40 BN cylinder oil has been used but has been restricted to very low running hours and under running-in conditions. It is considered that the lack of sulphur in the fuel means current technology cylinder oils are overbased, leading to excessive additive related deposits on piston, combustion chamber, exhaust valves, turbocharger and exhaust passages. Future formulation technologies will likely ‘break the link’ that has existed in the past with fuel sulphur versus BN. Therefore sulphur will likely cease to be the defining factor for lube oil alkalinity reserve.

Other factors will mainly influence the selection of the lube oil, as the current trend for variable steaming means the formation of acids which still require a level of neutralisation. Alternative formulations and chemistries will likely emerge in order to best deal with effective lubrication when operating with very low sulphur distillate fuels.

<u>Four Stroke Specific</u>

Experience with distillate fuel in medium-speed engines is already available and lubricants for this application are already in the market. Such lubricants typically have a BN of 12-20 and no detergency for asphaltenes. The use of a cleaner fuel will cause lower contamination of the lubricant and offers the possibility to optimize and adapt the oil system to this lower contamination. Smaller oil volumes, lower oil consumption and less effort for cleaning the oil are options arising from this scenario. In some rare cases using this fuel may lead to the formation of liner lacquer which coats the liner surface and can lead to higher lube oil consumption. Lacquers are largely a function of combustion characteristics and fuel quality (aromaticity, distillation properties) and the effects depending on the load profile of the engine.

Please refer to section 1.5 for information on bio content contamination.

1.3 High Sulphur HFO with scrubbing

Fuel	Lube
Fuel with either • worsening quality e.g. visbreaking, or conversely • improving quality e.g. less cutting back lower cat fines, reduced instability	• BN to match sulphur • Improved detergency may be needed • Still need "high" BN • Need to consider additive impact on after-treatment systems

This fuel can consist of HFO with any sulphur content, which may in some cases exceed 3.5% (based on the sulphur content of current crude oils and current refining practices). Although current IMO regulations state that fuel with >3.5% sulphur may not be marketed, this is currently the subject of debate and may be changed. Current and future IMO legislation allows the use of such fuels provided exhaust emission cleaning equipment is used that is capable of reducing the stack emissions to an equivalent SO_x level of that produced by fuels stipulated by global and ECA caps. Incoming legislation will change the supply/demand balance and the result will be that high sulphur HFO's will drop significantly in price, leading to good business cases for installing abatement technology. Due to no requirement for cutter stock to achieve target sulphur or viscosity limits, this fuel may be lower in cat fines. Current engines are capable of consuming this type of fuel as standard. However continued consistent use of >=3.5% may become more widespread for vessels installed with abatement technology equipment.

Two Stroke Specific

With the on-going economic need for variable steaming coupled with the desire for low oil feed rates this means that the use of current high BN (=>70) cylinder oils is set to continue. It may become more feasible to actively match BN to fuel sulphur content, but the impact of variable operating conditions, including the use of the scrubber system itself may lead to a need to increase the overall performance of the lubricant.

Four Stroke Specific

This scenario allows the use of fuels such as those currently used today, therefore there will not be significant new demands on the lubricant and todays lubrication system will to a great extent remain as is. In combination with low lube oil consumptions modern engines have, this will demand the use of high BN lubricants (50 mg KOH/g or even higher) or will require more regular oil changes at reduced intervals. Experience with such ultra-high sulphur fuels are available from marine applications before the 3.5% sulphur limit was introduced and from stationary applications of marine engines. However, the evolution of engine technology could lead to unexpected outcomes when operating on higher than normal sulphur content fuels.

1.4 Gas – LNG/LPG

<table>
<tr><td rowspan="3"><u>Fuel</u>
• Assume zero sulphur
• Assume up to 100% gas (incl. spark ignition engines)
• HP & LP injection systems</td><td><u>Lube</u>
• Low ash is dominant feature</td></tr>
<tr><td><u>Two Stroke Applications</u>
• 2 stroke experience is lacking
• Lower BN cylinder oil likely to be required</td></tr>
<tr><td><u>4 Stroke Applications</u>
• Oxidation and Nitration may be an issue in 4 stroke crankcase oils</td></tr>
</table>

Gas as a marine fuel is receiving greater interest due to its current low price and compliance with future IMO emissions limits with respect to both SO_x & NO_x. Gas does not contain sulphur.

Impacts on Lubrication:

This depends to some extent on the percentage of gas that is burned in the engine. If 100% gas then the type of lubricant required is quite different to those utilized for liquid fuel use. Typically low ash (low BN) oils are needed in order to avoid deposition on engine components.

Two Stroke Specific

At present 2-stroke pure gas engine technologies are not being developed but technologies of 2-stroke dual fuel engines are already established although not yet in marine service. Basically, either high gas pressure or low gas pressure technologies could be used. In both cases to operate on LNG as the main fuel, either a HFO or a distillate fuel is used as pilot fuel to ignite the LNG-air mixture and to initiate the combustion process.

Four Stroke Specific

There is a lot of experience with low ash oils in gas engines, and lists of recommended oils already exist. However for mainstream marine use, it is considered that a proportion of liquid fuel is required, for either pilot injection, or as backup emergency fuel when there are technical problems with the engine or when gas is not available, or when running on part load when use of gas is not efficient or reliable. This means that compromises must be made in terms of selected oil which may be based on the quality of the 'worst' fuel in use. This will be discussed in detail in a following chapter. Operation on natural gas only or with liquid fuel only as pilot fuel is well understood from power generation applications. Low ash gas engine lubricants are commercially available. These oils have a low BN of approximately 5. Because of the use of a clean fuel, smaller oil volumes, lower oil consumption and less effort for oil cleaning is required compared to HFO operated engines today.

1.5 Biofuel (B100)

Fuel	Lube
• May be used in some niche product tankers • Acid Number may be a problem for fuel equipment	• Same lubricant as for distillates or gas
	Two Stroke Applications • Same lubricant as for distillates
	4 Stroke Applications • Contamination of 4 stroke crankcase oil with “unknown” fuel type (potential for polymerization) • Residue, sludge & oxidation possible

100% unprocessed biofuel (rapeseed oil, palm oil, soya oil, jatropha etc.) are unlikely to be used in marine applications apart from potentially in vessels that transport such cargoes. These fuels are almost zero sulphur, but can have high Acid Number (low pH) which can impact fuel delivery systems.

Two Stroke Applications

There is very little experience with 2-stroke stationary engines powered with biofuels and this explains why there is no offer of dedicated formulation on the market. However, the requirement for the lube oil performance is directly related to the organic acids resulting from the biofuel combustion in terms of alkalinity reserve and detergency capability.

Four Stroke Applications

Operation on various biofuels is known from several power generation applications. The lubrication is similar to operation on diesel fuel, except for modified parameters being monitored in used oil analysis. Different test methods for indications of fuel dilution may be needed and considerations of the impact of such contamination on the condition of the oil.

A problem that may arise when these types of fuels, or mixtures of regular fuels and biofuels are used, is excessive accumulation in the engine oil. This is a phenomenon that is well known from high speed engines as used in trucks, agriculture or for small power generation units. Even in the field of passenger car engines the common mixture of up to 10% FAME and regular diesel fuel (B10) can cause problems arising from excessive fuel dilution. In general vegetable oils have a flash point above 200°C and even esterified FAME (fatty-acid-methyl-ester) which can be used like regular diesel fuel still has a flash point above 160°C. Petroleum based fuels and even HFO have much lower flash points which indicates a higher amount of low boiling point compounds. Fuel always enters the engine oil during operation, but a lot of the fuel compounds vaporize at the typical operating temperatures; whereas for most biofuels this is not the case. Therefore biofuel will accumulate to a much higher concentration in a shorter period of time compared to regular fuel operation. As a consequence the observation of biofuel content in engine oil is a key element for safe operation in order to avoid negative effects through excessive dilution, such as:

- Change of viscosity and dilution of additive level
- Negative reactions between biofuels and mineral oil such as polymerization

1.6 Crude Oil

Fuel	Lube
Challenges that need various solutions compared to refined fuels: • Low flash point • High vapour pressure • High salt content • High H_2S content • High pour point / cloud point / CFPP	• Similar/same lube as used in distillate or HFO operations

Crude oil is sometimes used in remote engines utilized for driving pumps on land based pipelines. Running on crude oil is more expensive than HFO and is unlikely to be widely used as marine fuel due to safety considerations. The quality of crude oil varies widely by location (crude source).

Impacts on Lubrication:

Similar lubricant as used in distillate or HFO applications. No additional concerns.

1.7 Emulsions & Water Technologies

Various "water" technologies exist or are in development. These can be in many forms, and can consist variously of:

- Refinery residue emulsions
- HFO emulsions
- Crude oil emulsions (e.g. Orimulsion)
- Distillate emulsions
- Water in Fuel (WIF)
- Direct water injection
- Humid Air Motor (HAM)

All these techniques introduce water into the ignition and combustion process which cool down and slow the rate of combustion; this may potentially impact the performance required of the oil and also affect the physical oil film. Conditions in the combustion chamber may become more corrosive, with changes to the acid dew point and additional water precipitating acids under different conditions to those of conventional fuels.

Potential Problems:

- Problems at start and when manoeuvring
- Oil-in-water = problems in fuel pumps – poor lubrication
- Fuel system corrosion
- Differing acid dew point
- Colloidal separation
- Breaking of emulsion
- Oil/water interface allowing bacteria to multiply

Impacts on Lubrication:

If it can be assumed that the emulsion / water technology produces complete combustion as would be expected from conventional fuels, then the lubrication would be the same as per the requirement for the base fuel used without water. If the combustion process is not ideal however, then the lubricant cannot be expected to perform under such extraneous conditions. Crankcase oil separation systems need to be capable of handling potential water contamination.

1.8 "Exotic" Fuels

There are a great number of fuels that are in the experimental/prototype stage, ranging from different plant oils, fish oils, methanol, aviation fuel etc. All will have a unique or similar requirement for cylinder lubrication, however as there are practically no commercial worldwide operation or experience they are not discussed in this document.

2 Combination Scenarios

In 2015 the current ECA's transition to the next stage of the legislation and ships transition from the present "dual fuel" combination of regular HFO with 1.0% sulphur HFO, to the new scenario of regular HFO and 0.10% sulphur fuel. This is a much more severe contrast of fuel types, meaning engines having to tolerate transitioning between greatly contrasting fuel types on a regular basis.

Some future common combinations are likely to be:

- HSHFO & LSHFO (present situation)
- HSHFO & <0.10% sulphur marine fuel (post 2015)
- Residual and distillate fuels of < 0.50% & <0.10% (post 2020/2025)

In addition to those above, emerging technology and NO_x legislation means that natural gas will also be a potential fuel to add to the combinations.

In the table below, severity ratings are applied are from 1 – 10 where 10 is the most severe contrast of fuels in terms of lubrication difficulty, e.g.

- combination of HFO and Gas is rated 10 as the difference in lubrication requirements may lead to issues that need to be addressed;
- the difference between de-sulphurised HFO and RMA 10 is very limited and so lubricant requirements are not considered significant

It is unlikely that if crude oil or B100 are used as fuels that they would be used in combination with other fuel sources. If this eventuality does occur then it should be dealt with on a case by case basis.

Very clearly, the combinations that include either HSHFO or Gas are the most complex.

	High S HFO	De-Sulph HFO	RMA 10	Dist 0 – 0.5	Gas	B100	Crude
Crude	×	×	×	×	×	×	✓
B100	×	×	×	×	×	✓	
Gas	✓10	✓7	✓5	✓3	✓		
Dist 0 – 0.5	✓7	✓3	✓2	✓			
RMA10	✓3	✓2	✓				
De-Sulph HFO	✓3	✓					
High S HFO	✓						

2.1 The gas engine case – dual fuel engine

As LNG does not contain sulphur, dual fuel engines require a cylinder lubricant with a low alkalinity reserve, or at least an alkalinity reserve in line with the nature of the pilot fuel. It is known that the ignition of the LNG-air mixture can incidentally occur because of ash or deposits responsible for hot spots. To avoid such phenomenon that can lead to engine failure it is preferable to use lubricants with limited ash content.

Recent published studies (3) have shown that abnormal combustion of the LNG-air mixture can be linked to the ignition of volatile fractions of the lubricant itself. Engine failures due to high peak pressure are foreseen if such a phenomenon is not controlled and the lubricant formulation has to be fit for purpose when operating in gas mode. It is significant that depending upon sourcing, LNG ignition properties as defined by the Methane Number can vary widely.

In this scenario the engine may run on:

- 100% HFO, or
- 95-99% Gas (1-5% pilot HFO or MDO), or
- Any ratio of the above.

The engine may receive either high pressure gas (200 – 300 Bar) and run according to the 'Diesel' cycle, or with low pressure gas (6 - 20 Bar) according to the 'Otto' cycle.

Two Stroke

If any significant portion of the fuel is HFO then a cylinder lubricant will be needed to deal with HFO operation as per present day requirements, to appropriately match the level of sulphur in the total fuel input. When switching to predominantly gas operation, a different lube oil type is likely to be required with a lower alkalinity level, coupled with the need to reduce potential ash forming deposits and to avoid abnormal combustion.

However, a dual fuel 2-stroke engine aims to provide flexibility on the proportion between LNG and HFO to cope with the economic needs of the vessel operation. It is also necessary to be able to switch immediately to 100% HFO mode for safety reasons. Therefore the cylinder lubricant specifications have to be in line with the requirements of both flexibility and safety.

It is too early to define properly the characteristics and the performances of such lubricant due to insufficient experience of 2-stroke dual fuel engine operation. Therefore we have to consider different ways to lubricate the cylinder units of these engines. For example, the following are potential approaches:

1. Switch between two lubricants (one for gas and one for liquid fuel operation).
2. Two cylinder lubricants could be combined during the engine operation, based on the LNG/HFO ratio. One lubricant could be specified to deal with HFO, that is to say with a sufficient alkalinity reserve among the other required performances. The other lubricant would have to be mainly a low ash product to fit with the gas operating mode. However one can easily envisage the complexity of both the lubrication system required and the management of the lubricants in operation.

3. One cylinder lubricant, able to provide sufficient alkalinity but without reaching critical ash content for engine reliability when running on gas mode. This scenario supposes to implement a new formulation approach driven by the use of ash-free additives or ash modifiers.

Four Stroke

The experience of operating four stroke engines in dual fuel mode is considerably more advanced than with two strokes due to shore based applications and also from marine engines in LNG tanker service.

Operation on HFO requires a high lube oil base number (usually accompanied by a high ash content) and good asphaltene detergency. These are not required in gas operation. The high ash content can be critical for operation on gas, because lube oil ash deposits in the combustion chamber can cause misfiring of the engine and knocking. In a fuel flexible operation mode oil changes when switching fuel is not possible. Therefore the lube oil base number must be sufficient to neutralise the acid combustion products from heavy fuel combustion but low enough to minimize lube oil ash deposits causing engine knocking. Engine design with a high tolerance for deposit causing knocking is important. Fuel flexible lean-burn DF engines have proven that they can be operated safely on a BN 30 - 40 lubricant while running in gas mode. If future engine design moves to stoichiometry to improve fuel efficiency, there will be an increase in the risk of abnormal ignition and lower ash oil with high neutralisation capacity will be required. Low ash oils will always be preferable for gas engine operation.

2.2 Combination of High Sulphur HFO and Low Sulphur Distillate

The immediate case before us is the imposition of the next step in the IMO legislation for ECA's in 2015. Large numbers of ships will be forced to switch between fuels with distinct differences:

- HFO with an average 2.5% sulphur (according to IMO-MEPC 2012 statistics), but also as high as 3.5%
- Distillate fuel (mainly) of 0.10% sulphur maximum, but may be less than 10 mg/kg sulphur

Two Stroke:

There is already considerable experience of these issues with four stroke engines, but for two stroke this is very new territory and there is little experience with modern two stroke engines. In previous years, older generation engines used to switch to distillate prior to port entry, but this was for very limited running hours. Modern engines do not have this requirement and only generally switch to distillate prior to any significant maintenance or off hire period. There is also some experience from the California (CARB) zone entry but that only applies to 24 miles in / out, resulting in a limited running time, say 3 or 4 hours. We can speculate on the impacts but all need to be quantified by experience. Here we can only raise awareness of the potential problems.

The main problem envisaged is considered to be a consequence of the mis-match of the in-use fuel sulphur content with the concurrently used cylinder oil BN and ash content (amount of additivation). Of concern is the length of time over which this may occur, which will often be in excess of 100 running hours for ships transiting ECA's, but also of concern to ships permanently based in ECA's where the minimum commercially available cylinder oil BN is 40.

Primary problems:

- Liner polishing
- Liner and piston ring corrosion
- Or both

Because of the immediate transition of fuels when crossing an ECA boundary and the way the fresh lube oil is delivered to the cylinder, the mis-match in chemical reactions takes place almost immediately, with a rapid manifestation as follows:

- o High sulphur : Low BN = Corrosion of piston rings and liners
- o Low sulphur : High BN = Ash deposits on piston crowns and top lands

Ideally, when the switch in fuel type is made then there should be a concurrent switch of low BN and high BN lube oil as recommended by OEM's. From 1st January 2015 the need to switch oils will be necessary, with only a few hours tolerance, rather than a few days. Certainly in the early days it will be necessary to make regular component inspections in port via the scavenge space in order to ascertain the conditions concerning deposits or corrosion during the first few ECA transitions.

An alternative view put on the market since 2008 is the single-cylinder oil solution. This alternative to the use of two lubricants with high and low alkalinity reserve has to be considered as a solution of lubrication post-2015. A single-cylinder oil in which ash-free additives could substitute the current calcium based additives might provide the ability to operate engines either on high sulphur HFO or on very low sulphur distillate because of limited ash content, assuming obviously the alkalinity reserve to be set properly considering both the HFO sulphur content and the engine operating conditions.

It should be noted that when confronted with the high relative costs of 0.10% sulphur fuel, it will be natural for operators to immediately reduce engine load (vessel speed) to the absolute minimum in order to consume less fuel in the ECA area. In most engines (including latest designs) there is an upwards correction in lube oil feed rate which means that the specific (adjusted) feed rate will be dramatically higher than the "headline" feed rate. This will lead to over-lubrication and potentially a greater excess of additives present in relation to the fuel sulphur content. It is known that conventional cylinder lubricants, as pointed out above, are prone to generate ash deposits and carbonaceous deposits in case of over lubrication or mismatch between BN and fuel sulphur content, leading to liner polishing. The use of new formulations and chemistries might help the limitation of ashes but also of deposit build-up when the engine is over-lubricated.

However, whatever the lubricant is, because of the increase of constraints for the engines and because of the multiplication of their operating modes it is recommended to implement a regular checking process, combining both scavenge drain oil analysis and visual inspections.

Four stroke:

Although a low BN of 12-16 is sufficient for operation on low sulphur distillate fuel, medium-speed engines are very tolerant regarding the usage of high BN lubricants even when high BN is not required. Operation on BN 40 or even BN 50 lubricants while running on low sulphur distillate is acceptable for most engines for several hundred hours without any operational difficulties. For longer operation periods it is recommended to adopt the oil BN to the fuel by using BN 20 or BN 30 lubricants as top-up oil instead of BN 40 or BN 50 lubricants while running on low sulphur distillates, but it is essential to ensure that alkaline reserve is high enough when operation on HFO starts again. The lube oils with different BN are advised to be from the same brand to ensure compatibility. Since in four stroke DF engines lubricating oil can't be changed when fuel quality changes over from gas to liquid fuel or vice versa, lubricating oil quality shall be chosen from "the worst" fuel quality point of view.

Monitoring used oil quality might require additional characteristics. While contamination of the lube oil with heavy fuel is indicated by an increase in viscosity, contamination with diesel fuel can compensate this effect and can stabilize the lube oil viscosity although fuel contamination is increasing. Therefore the necessity of changing the oil can be masked when there is a combination of HFO and distillate contamination which stabilizes the viscosity.

Some oil analysis labs are already measuring the asphaltene content which quantifies the contamination with heavy fuel. Nevertheless clear limits for the contamination with asphaltene are so far not defined.

Experience has to show if new oil change criteria must be defined or if even new analysis methods have to be developed to monitor the contamination with a mixture of different fuels.

2.3 Combination of Low Sulphur HFO and Low Sulphur Distillate

Two stroke

The limitation of sulphur content to 0.5% in HFO that could be used after 2020 or 2015 will drive the cylinder lubricant specification. Assuming that current technologies and operating modes will continue after 2020 the need for neutralization capability might require a BN of 40. The cleanliness of the piston ring pack of engines running on this fuel will still require a lubricant with high detergency level.

Four stroke

Using RMA 10 with 0.5 % sulphur does not require a lube oil with a BN of 40 or 50. BN of 16 to 30 is sufficient for most engines. Nevertheless because of the residual components in the fuel a good asphaltene detergency is required. Therefore a heavy fuel capable lubricant with a BN of about 20 and a good asphaltene detergency will probably be the best choice for both operation on RMA 10 and distillates.

3 Two Stroke Engine Inspections and Diagnosis

During inspection the piston is divided into different sections:

Top Land

- Top Land (or crown land) is the vertical area above the 1st ring groove.

    i) It should be ensured that deposits do not build up excessively to the extent that they rub against the liner, disturbing the oil film and leading to polishing of the liner surface, and prevent free gas flow to the piston rings.

Ring Lands

- Ring Lands are the vertical areas between the piston rings and they are referred to as 1st, 2nd and 3rd ring land depending on the position. They should as a general rule be without any deposits, however, it is common to find deposits especially on the 1st ring land that need to be monitored during the inspection.

Ring groove cleanliness

- It is important that the ring grooves are clean and free of deposits in order to ensure free ring movement:

    a) If the cleanliness condition is good, then feeler gauges will be easy to insert into the groove.

    b) If the cleanliness is not so good then normally there will also be deposits on ring land and potentially deposits on the ring backs (which obviously cannot be observed via a scavenge port inspection). Excessive groove and ring back deposits can result in a restriction of free ring movement, with the worst case scenario being the ring sticking or becoming 'packed out' due to deposits behind the ring, and that will lead to scuffing.

In general the influence of the detergent/dispersant properties of the oil and their impact on piston cleanliness is something that can change within relatively short 24 - 48 running hours of running on a different fuel type, and thus needs careful monitoring, particularly in the early days of the 2015 regulations coming into force.

Drain oil analysis

Scavenge drain oil analysis is an efficient way to monitor the current wear condition of 2-stroke engines. Two main parameters among others can be followed-up: the iron content and the residual BN. The first is an indicator of the wear behavior whilst the second provides information about the alkalinity reserve of the cylinder lubricant.

The interest in drain oil analysis is to provide an individual view of each engine monitored. Provided samples are properly taken (sampling procedure), on a regular basis and/or each time there is a change in the engine operating condition (fuel type, engine load change, lube oil feed rate change, climate change...), the trends of the parameters evolution can be monitored and used to optimize lubrication.

Interpretation of drain oil analysis in relation to the wear (corrosive or abrasive wear) requires a good knowledge of the engine and of the influence of the various parameters that can affect the results of the analysis. It is necessary to analyse the drain oil coming from all the cylinder units to have an overview of the whole engine because of cross contamination between cylinders. It is also fundamental to sample the system oil to be able to quantify how much the drain oil is contaminated due to stuffing box leakages. Apart from the validation of the parameters measured and monitored over time, checking the stuffing box efficiency is a good indicator for maintenance management. Any changes of lube oil feed rate must be applied gradually after checking also visually the condition of the liners, of the pistons and of the ring packs. The drain oil monitoring process must be continued to check the effects of the change applied.

4 Conclusions

It is clear that the lubrication of marine engines is entering a new era as a consequence of environmental legislation. Experience in using the incoming low sulphur distillate and gas fuels is extremely limited with 2 stroke engines, with operators not choosing to use these expensive fuels until they are compelled to do so. Theory and practical demonstration shows that engines will initially run successfully on such fuels, however what is completely unknown is the long (or even short) term durability of components with so far untried lubricants that are still at the experimental stage of development. It has thus far not been possible to run durability tests whilst there are no engines running on such low sulphur fuels.

With the above in mind, as said in the introduction, the intention of this paper is simply to provide an aid for operators to make observations in service and adapt to the new operational parameters as experience is gathered and as new lubricant formulations come to market and are tested in practical service. It is the intention of the CIMAC Lubricants Working Group to update and provide members with more specific guidelines once the legislation is embedded and substantial operational data has been gathered.

5 References:

1. ISO 8217:2012 “Petroleum products – Fuels (class F) – Specifications of marine fuels”
2. CIMAC fuels working group document “Guideline for ship owners and operators on managing distillate fuels up to 7% FAME (Biodiesel), 2013
3. S. Yasueda, L. Tozzi, E. Sotiropoulou, Paper n° 37, Proceedings of the 27th CIMAC Congress, May 2013, Shanghai

6 Acronyms and Abbreviations

B100	Biofuel, with 100% bio content
B7	Biofuel, with 7% bio content
BN	Base Number, measure of alkalinity of lubricating oils in mgKOH/g
CARB	California Air Resources Board
Cat fines	Catalyst Fines, hard abrasive aluminium silicon particles, a bi-product of the refining processes
DMA	Distillate fuel as per ISO 8217 specification. Clear and Bright.
DMB	Distillate fuel as per ISO 8217 specification
DMC	Now obsolete distillate fuel specification, contains residual components, replaced by RMA 10
DMZ	Distillate fuel as per ISO 8217 specification. Clear and Bright. With additional viscosity control
ECA	Emission Control Area, as defined by IMO
FAME	Fatty Acid Methyl Ester, a form of bio-fuel
HFO	Heavy Fuel Oil, composed of refinery residues
HSHFO	High Sulphur Heavy Fuel Oil
IMO	International Maritime Organisation, part of the United Nations
IMO – MEPC	International Maritime Organisation – Marine Environmental Pollution Committee
ISO	International Standards Organisation
LNG	Liquefied natural Gas
LSHFO	Low Sulphur heavy Fuel Oil
MDO	Marine Diesel Oil, a generic term for marine distillate fuels without specification
NO_x	Oxides of nitrogen
OEM	Original Equipment Manufacturer, in this case the engine designer
RMA 10	A classification of residual fuel as per ISO 8217, previously known as DMC
Scrubbing	Exhaust gas cleaning system to remove pollutants
SO_x	Oxides of sulphur
ULSD	Ultra Low Sulphur Diesel, normally for automotive use. Typically <50 ppm (0.005%) sulphur

Imprint

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