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Field experience with Shell Alexia 40 XC in dual fuel two-stroke engines combusting alternative fuels

Lubricants

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ABSTRACT

As the latest generation of 2-stroke low speed marine engines operate with higher pressures and temperatures to achieve better efficiencies, it has been demonstrated that using a higher performance lubricant with better engine cleanliness and wear protection is beneficial. With the efforts from the marine industry to play a part in decarbonizing and reducing greenhouse gas emissions, it is clear that more ship owners are open and looking for dual fuel marine engine options as they continue building new vessels. Currently available options in the market for new-buildings consists of conventional engines and dual fuel engines. Dual fuel engines are now designed to operate on conventional and alternative fuels which include: LNG, Methanol, Biofuels and Ammonia. In coming years the marine industry will also maintain a large fleet of vessels in which owners will need to look into the space of retrofitting the engines to operate on lower carbon fuels or even operating with drop in biofuels or blends thereof as an alternative to meet the Carbon Intensity Indicator (CII) rating.

In this paper, the authors describe the field experience with Shell's 40 BN cylinder oils, Shell Alexia 40 and Shell Alexia 40 XC in several engine models and a variety of improved piston ring pack designs operating on alternative fuels to meet CII ratings. Cases with LNG, Methanol, biofuels and even distillates are presented as proof of suitability of these lubricants to cope with a variety of fuels in modern marine dual fule 2-stroke engines.

1 INTRODUCTION

In this paper, the authors describe the field experience with MAN Cat I BN40 cylinder oil Shell Alexia 40 and MAN Cat II high performance BN40 cylinder oil, Shell Alexia 40 XC, in several engine models meeting Carbon Intensity Indicator (CII) ratings and with a variety of improved piston ring pack designs. Engines have been operating on alternative fuels such as LNG, Methanol, biofuels and even distillates; these cases offer proof of suitability of these lubricants to cope with a variety of fuels in modern marine dual fuel 2-stroke engines.

Over the years, engine manufacturers have been focusing in making their engines more fuel efficient which have directly impacted the increase of pressures and temperatures in these engine designs. Furthermore, with the need to reduce CO_2 emissions, many ship owners and operators have been looking at alternative fuels, in most cases alternating with marine diesel fuels, experience is still relatively limited, thus the need to document these cases to identify additional lubrication needs.

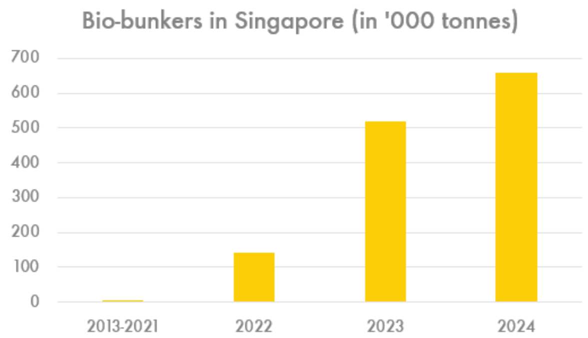


Figure 1. History of bio-bunkers' sales in Singapore in '000 tons

Since 2021, the uptake of biofuels has been increasing steadily and even more in 2024. Sales of biofuel blends in Singapore surpassed 658,000 tons in November 2024, compared to 518,000 tons during 2023 (Figure 1). The order books of methanol powered dual fuel engines have also increased compared to previous years. With the FuelEU Maritime Regulation coming into force since January 1st, 2025, many vessels calling the European ports are forced to use biofuels as a drop in fuel. MAN Energy Solutions recommends 40 BN Cat II Cylinder Lubricants for modern fuel efficient engines also when operating on alternative fuels [4]. Shell Alexia 40XC which was designed to be a higher performing product, naturally fits into the picture to provide the required cleaning capability, especially for the newer fuel-efficient engines [5].

2 LEARNINGS FROM HSFO AND VLSFO OPERATION

2.1 High Sulphur Fuel Oil Operation

Since the early 2010's, cold corrosion has become a regular occurrence on many modern large two-stroke marine engines due to slow steaming, engine design and tuning. Furthermore, the engine manufacturers introduced engines with super long strokes to improve fuel efficiency. These engines with cold corrosion can suffer from higher wear rates (Figure 2), higher running costs and downtime, shorter time between overhaul, etc.

Though the cases of cold corrosion have reduced with the adoption of compliant fuel with <0.5%S, customers with scrubbers installed in their vessels should still pay close attention to the engine condition as the high sulphur fuels supplied now to the scrubber fitted vessels are typically >2%S. Use of either BN100 (Shell Alexia 100) or BN140 (Shell Alexia 140), depending on application, has been proven to be beneficial to tackle cold corrosion.

Figure 2. A corrosive engine phenomenon with black spots formation

Cold corrosion happens when sulphuric acid in combustion gas reach and condenses (dew point) at the liner wall. To prevent this from causing premature wear, two things can be done:

- Prevent the acidic gas from condensing.
    - Changes to new engine hardware to increase liner temperatures help to prevent condensation.
- Neutralise the sulphuric acid, before it reaches the metal surface.
    - These have greatly supported these modifications to bring cold corrosion under control including higher BN cylinder oils, more cylinder monitoring (drain oil analysis), and revised feed rate advice.

When engines operating with HSFO and scrubbers alternate to e.g. biofuels, it is recommended to monitor carefully for excessive ash accumulation resulting from the high alkalinity in the lubricant and that is not needed for neutralization when no sulphur is present in the fuel.

2.2 Very Low Sulphur Fuel Oil Operation

Since adoption of the global 0.5% sulphur cap, two stroke low speed engine manufacturers have previously recommended BN40 lubricants for engines operating with VLSFO, thus matching the acid neutralization capability of the lubricant with the sulphur content of the fuel. However, the more widely and continuous use of the former generation of commercial 40 BN lubricants resulted in an increased number of observations of poor engine cleanliness in highly rated engines (Figure 3 and 4)

Figure 3. Heavy carbon deposits on the back side of piston rings can lead to collapsed piston rings and scuffing.

Figure 4. Heavy deposits formation on piston ring lands and collapsed piston rings.

Despite BN100 oils coping with the engine cleanliness in low sulphur applications, there are some concerns on the long-term use of these “high sulphated ash” products which can accumulate overtime along the exhaust gas path, etc. An example is presented in Figure 5.

Figure 5. Accumulation of calcium deposits along the exhaust gas path

Because of the above, it became necessary to develop new BN40 cylinder lubricants with higher cleaning ability. Shell Alexia 40 XC has been designed as a low-BN oil with a cleanliness benefit equal to BN100 oils so that it is the easy choice to improve engine cleanliness, engine reliability and onboard operational efficiency on <0.5%S fuel operation. From its characteristics and as recommended by engine makers, it is expected that this lubricant performs at high level also with alternative fuels.

3 MONITORING OF ENGINES ON ALTERNATIVE FUELS

3.1 Methanol

Methanol has certain characteristics which makes it suitable as a marine fuel. It is liquid at ambient temperature and does not require cryogenic facilities. Comparing it with conventional fuel, methanol also burns cleanly with practically zero sulphur content resulting in low particulate matters and soot emissions. An important aspect from cylinder lubrication is on the solvency of methanol. Close attention shall be paid to the cylinder lubricating film at the top of liner wall with methanol powered engines. Fuel reaching the oil film could lead to abnormal wear.

Table 1. Engines using methanol as alternative fuel

Engine	Feed Rates	Operating Pattern	Lubricant
5S50ME-C9-LGIM	0.8g/kWh	Methanol 85% VLSFO 15%	Alexia 40XC

Shell has been monitoring at least 8 vessels in a recent delivered fleet of methanol powered engines. These engines are supplied with the latest 3 ring pack from MAN ES. Vessels started from the recommended 1.5g/kWh breaking in feed rates according to schedule. A 0.8g/kWh feed rate was achieved within the running in period and piston ring assembly condition has been found in satisfactory. Table 1 summarizes conditions for this case.

Ring running in coatings should wear off after 1200 – 1500 hours according to OEM expectations. Figure 6 shows that the running in coatings were intact after 2,000 hours. Oil analysis for cylinder condition monitoring showed the total base number in the drain oil remained normal [2] and stable (almost at fresh oil level) throughout the methanol operation with minimal depletion of base number (Figure 7).This proves that with this high performing lubricant, and close to zero sulphur in methanol, the established wear rates are very low in comparison to MAN ES guidelines in this cases (Figure 8). Low wear rates are also proven from the low iron content in drain oil analysis.

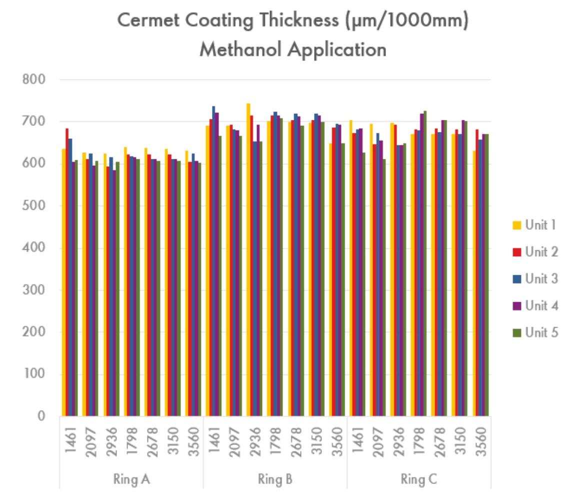


Figure 6. Cermet coating thickness measured throughout the monitoring of methanol powered S50ME-C9 LGMI engine.

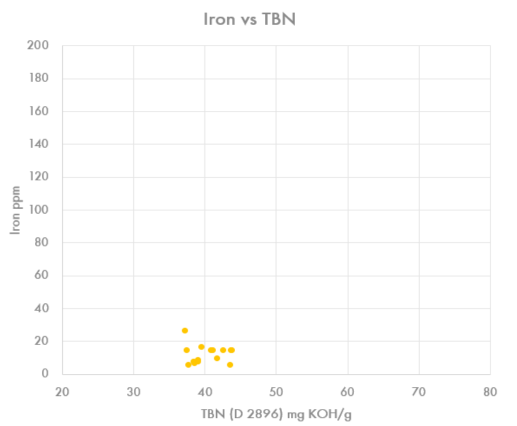


Figure 7. Iron vs Total base number in methanol application.

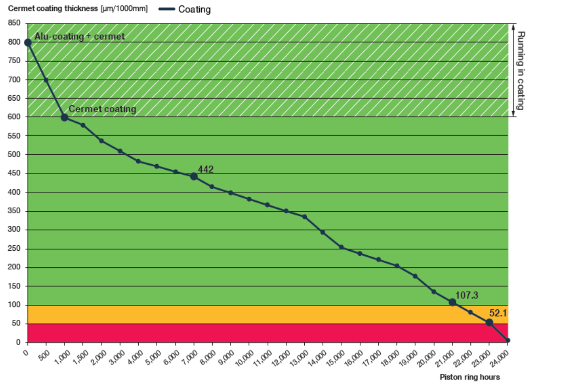


Figure 8. Coating thickness table from MAN ES SL2019-685 [1]

Figures 9 and 10 present impressions of cylinder condition after the 2,000h monitoring period.

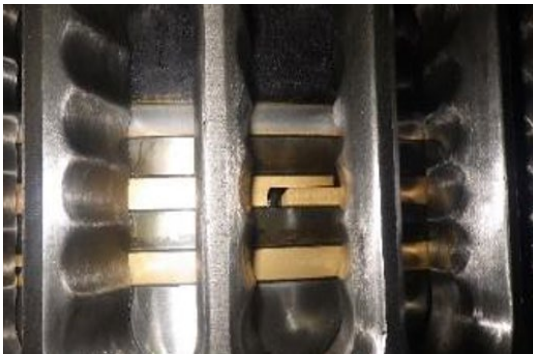


Figure 9. Piston ring packs after 2,000 hours with zero deposits, only slight discoloration on piston ring lands

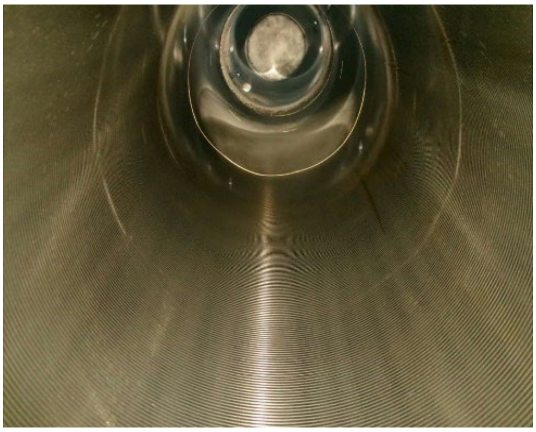


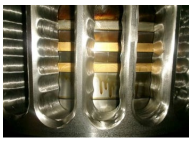
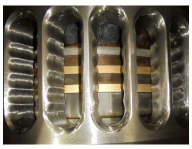
Figure 10. Clear wave cut marks on cylinder liner.

Figure 11. Only minor calcium carbonate deposits found on piston crown.

Figure 11 shows signs of calcium carbonate accumulated on the piston crown but within expectations, as the zero sulphur in methanol will barely consume the alkalinity of the cylinder lubricant. These calcium carbonate deposits have been stable throughout the entire monitoring period, with no signs of increment and this should not affect the engine operation as LGIM engine is based on a diesel cycle engine concept.

A clean piston ring pack with minimal wear in the units are observed and maintained with the use of Shell Alexia 40 XC in both sister vessels (Table 2) at different operating hours.

Table 2. Comparison between sister vessels using methanol.

Operating Hours	Vessel A	Vessel B
>1500 hours		
>2500 hours		

3.2 Biofuel B24

As the new generation of dual fuel engines will take some time to replace conventional single fuel engines in the market, the conventional fuel engines still occupy a big portion of the global fleet, leading to many ship owners and operators opting in for biofuels or fuels with bio-content to reduce carbon intensity. Biofuels are known to have stability issues due to the various types of feed stocks and blends. Furthermore, the oxidation stability of the biofuel could differ from different feedstocks. Fatty acid methyl esters (FAMEs) are the most used biofuel components in the marine industry, typically POME, UCOME, RME, SME etc.

Table 3. Engines using biofuel B24 as alternative fuel.

Engine	Feed Rates	Operating Pattern	Lubricant
7K98ME	0.7g/kWh	B24 22% VLSFO 78%	Alexia 40

Many ship owners have approached us to discuss suitability of cylinder lubricants with B7 up to B30 bio blends. To answer this question, B24 UCOME operation was monitored in a small group of vessels using these fuels. It was found that Cat I Shell Alexia 40 could handle this biofuel blend well in the cylinder units. Table 3 presents summary data for the case discussed in this section.

CL groove rings are installed in this fleet and these engines were lubricated with 0.7g/kWh operating at max 60% load. During operation with 100% VLSFO, Figure 12 shows that a thin layer of deposits can be found on the first ring lands of the units.

During the period of alternating between B24 and VLSFO, feed rates were maintained at 0.7g/kWh in these engines. Even with the low feed rates, the piston ring packs have shown improvement in terms of cleanliness with much lesser deposits (Figure 13). Minimal wear is observed referring to the cermet coating thickness trend (Figure 14) and low iron content in drain oil samples.

Figure 12. Piston ring lands with deposits (rough surface) and discolorations, running on 100% VLSFO with Shell Alexia 40.

Figure 13. Clean and smooth piston ring lands with some discoloration, running on B24 UCOME with Shell Alexia 40 (alternating usage with B24 and VLSFO)

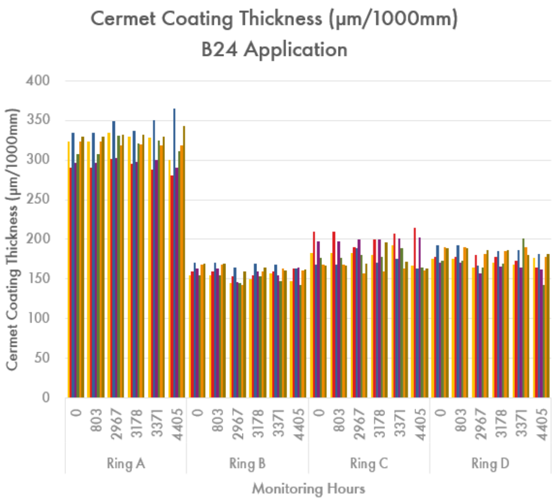


Figure 14. Cermet coating thickness measured throughout the monitoring of B24 application.

Good results have been observed in the drain oil analysis from these engines with some viscosity drops in some samples, but these are mainly caused by the dilution of system oil (Zn and P present). Total Acid Number was observed to have a slight increase compared to engine running on VLSFO. As FAMEs are also hygroscopic, we have noticed a small increase of water content in some batches of the drain oil samples.

This experience was made in a mark 7 engines. It is expected that higher efficiency engines will require a higher performing lubricant (MAN Cat II).

It is likely that the cleaning effect observed with B24 in the example is driven by the fuel blend composition/characteristics (Figure 15) with a lower residual fuel content and the amphiphilic nature of FAME molecules working as a “cleaning” aid.

ISO 8217:2010

			Specifications	Results
	BIOFUEL B24 (2010)		BIOFUEL B24	BIOFUEL B24
1	Density @15°C	kg/m³	Max. 991.0	931.4
2	Kinematic Viscosity @ 50°C	cSt	Max 380.0	45.62
3	Flash Point	°C	Min 60.0	>83.0
4	Pour Point - Summer Quanlity	°C	Max. 30	18
5	Micro Carbon Residue	mass %	Max. 18.00	5.63
6	Ash Content	mass %	Max 0.100	0.04
7	Water by Distillation	vol%	Max. 0.50	0.4
8	Sulphur	mass %	Marpol Max. 0.50	0.47
9	Vanadium (V)	mg/kg	Max. 350	15
10	Total Sediment, Potential	mass %	Max. 0.10	0.02
11	Aluminium (Al) + Silicon (Si)	mg/kg	Max. 60	60
12	Aluminium (Al)	mg/kg	Report	32
13	Silicon (Si)	mg/kg	Report	29
14	Zinc (Zn)	mg/kg	Max. 15	1
15	Phosphorus (P)	mg/kg	Max. 15	<1
16	Calcium (Ca)	mg/kg	Max. 30	29
17	Sodium (Na)	mg/kg	Max. 100	40
18	Iron (Fe)	mg/kg	Report	27
19	Lead (Pb)	mg/kg	Report	<1
20	Magnesium (Mg)	mg/kg	Report	5
21	Nickel (Ni)	mg/kg	Report	18
22	Potassium (K)	mg/kg	Report	2
23	C.C.A.I	-	Max. 870	819
24	Total Acid Number (Test Method A)	mg KOH/g	Max. 2.5	0.8
25	Gross Specific Energy	MJ/kg	Report	44.19
26	Net Specific Energy	MJ/kg	Report	41.67

Figure 15. Fuel analysis report for one of the B24 fuel samples.

3.3 LNG

In recent years, the LNG use as a marine fuel has been increasing significantly, since it has advantages over conventional diesel fuels, such as reduced emissions for SOx, NOx and CO_2. Table 4 presents summary data for the two the cases discussed in this section.

Table 4. Engines using LNG as alternative fuel.

Engine	Feed Rates	Operating Pattern	Lubricant
5X72DF	0.80g/kWh	LNG 95% MGO 5%	Alexia 40 Alexia 40XC

Since delivered, one of our current test vessels has been operating on Shell Alexia 40 with LNG as main fuel before we conducted a DF validation trial according to the Winterthur Gas & Diesel procedure [3]. Feed rate was set at 0.85 g/kWh for gas operation.

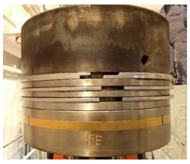
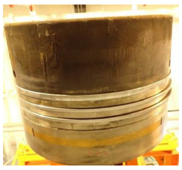
Before the formal validation trial, the selected test unit was observed to have very low cylinder liner wear, of only total 0.01 mm wear. This was measured on the test unit after 23,922 hours of normal operation. Running surface was in good visual conditions with honing marks well visible all the way to the top of the liner without wear ridge step.

Piston rings were also found in very good visual condition with some machining marks still present on running surface (Table 5).

Deposits on piston crown top land are minor and crown is clean above top piston ring. Crown grooves and piston rings were extremely clean, practically without deposits after 23,922 hours since installation.

We started the DF validation trial knowing exactly the condition expected at completion. To further challenge the oil, feed rates were reduced from 0.85 g/kWh to 0.8 g/kWh. The outcome of the 4,000-hour trial looks almost identical to the outcome we have observed in the 23,922 hours operation (Table 5).

Table 5. Comparison between different engine parts on Shell Alexia 40 at different operating hours.

Description	Scenario A Alexia 40 23,922 hours	Scenario B Alexia 40 4,000 hours
Piston ring packs		
Piston ring grooves		
Piston ring back		
Piston ring top		
Running surface		
Piston crown		

At the time of this publication, the DF validation of Shell Alexia 40 XC is in progress and due completion. At approximately 3,500 hours, piston ring packs in this validation test are looking like new, bright surfaces observed with no signs of deposits building up on the piston ring lands (Figure 16). The wave cut marks on the cylinder liners are still clear without signs of wear (Figure 17). Complete results of this test will be also presented at the *CIMAC Congress 2025, Zürich.*

Figure 16. Piston ring lands showing zero deposits after approximately 3,500 hours using Shell Alexia 40 XC with 0.8 g/kWh feed rate.

Figure 17. Cylinder liners showing clear wave cut marks after approximately 31,000 hours using Shell Alexia 40 and Shell Alexia 40 XC

Experiences have also been documented in the high-pressure engine design from MAN ES ME-GI lubricated with our MAN Cat II oil. Slightly more, but minor deposits have been observed to accumulate in the piston ring packs, if compared to the low-pressure engines. The examples below are taken from an engine operating between 0.6 g/kWh to 0.8 g/kWh with Shell Alexia 40 XC after approximately 2,000 hours in operation (Figures 18, 19 and 20).

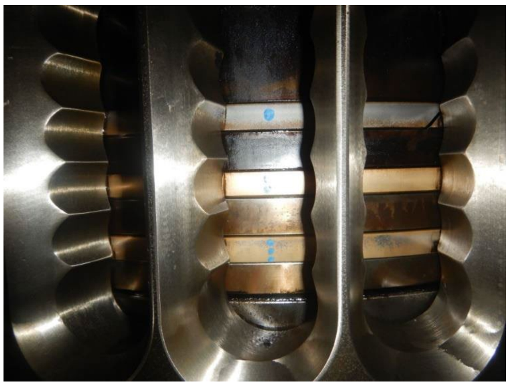


Figure 18. Piston ring packs of a ME-GI engine operating on Shell Alexia 40 XC

Figure 19. Close up of first ring of a ME-GI engine operating on Shell Alexia 40 XC

Figure 20. Close up of first piston ring lands in a ME-GI engine operating on Shell Alexia 40 XC with slight deposits on the piston ring lands.

3.4 Ammonia

With the maritime industry aiming to reduce greenhouse emissions by almost 70% over the next two decades, engine technology is being developed to utilize ammonia as an alternative fuel. Ammonia, although known for its toxicity, has the potential to be true zero carbon well-to-wake fuel if produced using renewable energy. It requires significantly less cooling to be stored in liquid form if compared to other fuels such as methane or hydrogen.

As almost every marine engine maker is gearing up for the launch of ammonia engines and conducting first engine tests, we have investigated some tribological aspects of cylinder lubricants under ammonia atmosphere searching for possible effects of ammonia on friction and wear protection properties of marine lubricants. It is expected ammonia to be burn in the diesel cycle and to combust clean, thus lubrication challenges might not differ greatly from other zero sulphur fuels with regard of cleanliness. However, given that some reports, including our own studies have identified some ammonia interactions with lubricant additives providing an anti-wear function, such as ZDDP and some alkaline detergents, Shell is currently researching on effects of ammonia on the latest generation of cylinder lubricants.

Figure 21 illustrates the laboratory rig utilized to screen and investigate tribo-film formation and anti-wear behavior of cylinder lubricants under a pressurized ammonia atmosphere. Relative results obtained for cylinder lubricants studied in this set up are presented below (Figure 22). Shell Alexia 40 XC, a commercial 40 BN cylinder oil containing ZDDP (300 ppm Zn) and a Zn free 20 BN cylinder oil prototype (aiming to reduce ash contributions from cylinder oil) were tested. From these initial results, it can be theorized that the commercial oil containing ZDDP sees its anti-wear properties more affected when tested under the presence of ammonia compared to the other oils or to the results obtained under a normal air atmosphere. Whether the differences represent a true concern of available cylinder lubricant technology remains unknown. Only engine testing can determine whether this effect is significant.

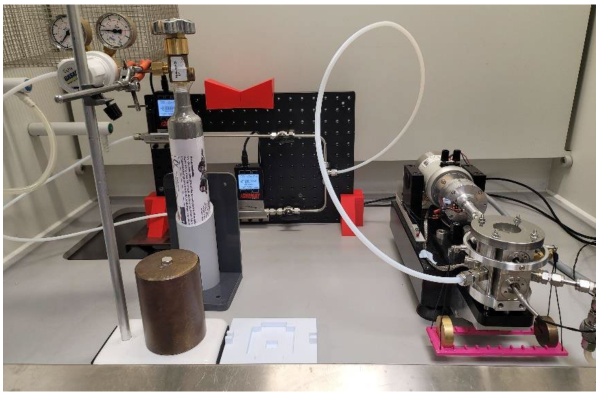


Figure 21. Pressurized chamber integrated in a high frequency reciprocating rig to analyze tribo-film formation for a ball on plate (immersed in lubricant) under air or ammonia atmosphere.

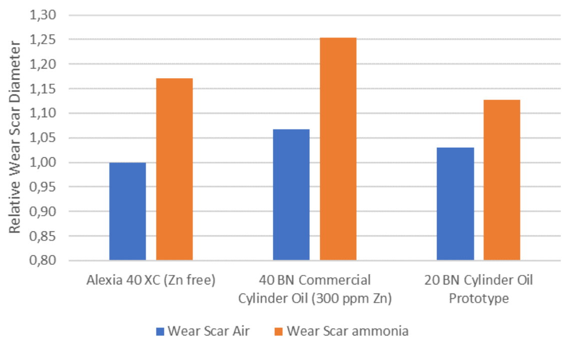


Figure 22. Relative results obtained for cylinder lubricants studied in for tribo-film formation and wear under air and ammonia atmospheres.

Our group has already seen lubricant behavior over a short engine running time in a 4-stroke engine operated with ammonia. No significant effects from ammonia were observed on the lubrication process or the lubricant properties of a standard trunk piston engine oil, except for a slight increase in base number. However, this experience was only made starting with fresh lubricant and effects are unknow on long-term running or with a lubricant that is also used for a different fuel mode in such an engine. At the time of publication of this paper, we expect to have also gathered short test experience in a 2-stroke engine to share first observations on Shell Alexia 40 XC in ammonia operation.

4 CONCLUSION

Both Shell Alexia 40 and Shell Alexia 40 XC have performed well within our expectations in various applications, including LNG, methanol, and biofuels blends. Although the lubricants have performed well, it is still highly recommended that onboard drain oil analyses, lab drain oil analyses and visual inspections aided by oil/engine condition monitoring tools (such as Shell LubeMonitor) are carried out according to the engine maker's recommendations to ensure that the engines are monitored closely and operating within limits.

In cases where signs of fouling are noted in the piston ring packs especially in the higher efficiency engines such as the MAN ES Mark 9 and above engines, it is highly recommended that Shell Alexia 40 XC to be used to maintain cleanliness in the units using compliant fuel.

5 REFERENCES

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