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Development of an Advanced Lubricant for Modern Gas Engines and Field Performance Confirmation

Lubricants

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ABSTRACT

Modern gas engines fuelled with natural gas can deliver a big contribution to compel towards a lower-carbon future. Natural gas is abundant, clean burning and results in far less CO2 emissions compared to other fossil fuels. Gas engines are well established in power and heat generation, are robust and offer fast response on start-stop and load change over, making them strong performers for peak demands. To fulfil the high efficiency of these modern gas engines also high-performance lubricants must be developed. For the oil development a good understanding of engine technology is required, and relevant development methods must be applied.

The increasing need for electric power is driving significant developments in engine technology that improve efficiency, reduce the emissions footprint and enable higher operational flexibility. To achieve higher efficiencies, engine manufacturers have focused on increasing power density by optimizing combustion at higher compression ratios through design changes and metallurgical development, e.g. shorter piston top land and steel pistons are now becoming more common. These highly efficient engines operate at higher Break Mean Effective Pressures (BMEP) with engine components withstanding higher operating temperatures. Under these operating conditions, some engine designs can be sensitive to knocking, making control of combustion chamber deposits (generally originated from lubricant ash) a key element for a reliable operation. To better control knocking risk and to meet particulate emission standards, lube oil consumption on these engines can by design be as low as 0.05 g/kWh.

The combination of higher BMEP, higher operating temperatures and low lube oil consumption results in higher levels of oil stress to the lubricant, accelerating its degradation. This is reflected in reduced oil drain intervals as condemnation limits are reached faster particularly in terms of oxidation, alkalinity depletion (TBN) and/or viscosity increase. Accelerated oil degradation can result in increased deposits especially in high temperature areas such as piston top and top ring groove that can lead to efficiency loss and piston running reliability issues.

The authors elaborate on several aspects of understanding lubricant degradation in modern gas engines and illustrate the strategies taken to improve lubricant performance through a comprehensive set of test results. The discussed data has been generated for non-synthetic lubricant candidates through a series of screeners including a single cylinder laboratory engine and field test that that lead to the market introduction of Mysella S7 N Ultra, Shell’s top tier gas engine oil. Moreover, performance of this lubricant has been demonstrated in modern highly rated field engines of different makers operating under severe operating conditions. The field data demonstrates significantly improved oil life aspects and superior deposit control in modern steel piston gas engines that have been prone to deposit build up with the previous generation of mineral gas engine oils.

1. GAS ENGINE TECHNOLOGIE EVOLUTION

Over the past two decades, engine designs have evolved to be more powerful and efficient. Newer engines operate at higher brake mean effective pressures (BMEP) with engine components also withstanding higher operating temperatures. Figures 1 illustrates the increase of the electrical efficiency and selected BMEP values for natural gas engines over the years. The higher BMEP correlates directly with the increase of the power output.

Whereas the efficiency gains have been significant, and engines have been made more robust and powerful, lubrication has encountered some challenges. Newer designs expose the engine oil to higher operating temperatures and pressures, at the same time the lubricant consumption has been significantly reduced (to prevent knocking risk and to assist emissions control). The net effect on the lubricating oil has been an increase in oil stress [1]; this has resulted in accelerated oil ageing and thermal degradation, reflected in higher oxidation rates and deposit build up issues in the piston assembly.

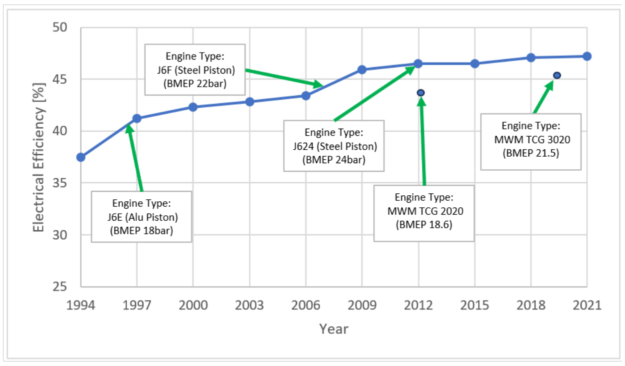

Figure 1. Illustrate the increase of the electrical efficiency and selected BMEP values for natural gas engines over the years [2] [6].

2. INFLUENCE OF HIGHER BMEP ON OIL DEGRADATION

The increase in engine BMEP has a pronounced effect on oil ageing. Figure 2 illustrates the effect of BMEP increase on typical oil analysis data for a reference high performance lubricating oil. It can be easily concluded that higher combustion pressures lead to increased lubricant oxidation rates.

It shall be noticed that the effect of higher BMEP cannot be looked at in isolation, as combustion chamber design changes, including piston metallurgy (e.g. aluminum or steel), appear to influence oil degradation. More detailed background information is described in our previous paper presented at the 2019 CIMAC Congress in Vancouver [3].

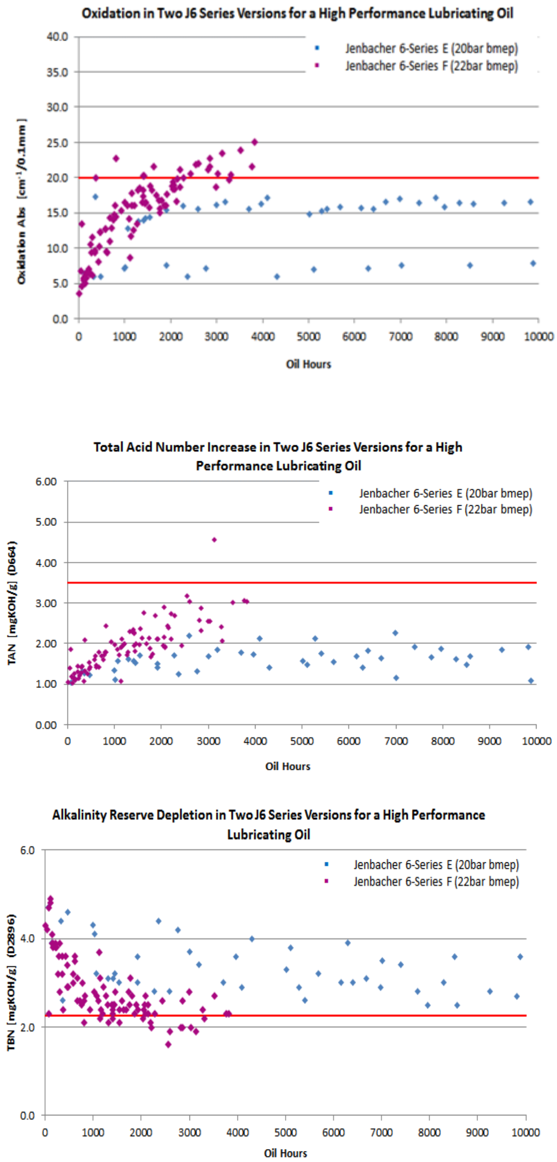

Figure 2. Effect of BMEP increase on typical oil analysis data for a reference high performance lubricating oil run on 20bar and 22bar J6 engines. Oxidation and TAN increase and BN depletion are more pronounced in the 22bar design.

3. INFLUENCE OF HIGHER TEMPERATURES AND PRESSURE ON DEPOSIT BUILD UP

Iron based alloys (steel or cast iron) are now common materials in pistons for very high BMEP engines as, in contrast to aluminum, these resist better high peak pressures and temperatures that over time can lead to piston crown deformation. As these iron alloys have lower thermal conductivity, pistons can experience higher temperatures in operation compared to aluminum, with a more pronounced effect on thermal degradation of the oil in direct contact with the piston assembly [4]. Deposit build-up in the high temperature areas of steel pistons has been commonly observed in the field with high BMEP engines and mineral base oil based high performance lubricants. Figure 3 illustrates deposit build up observations on steel pistons from different engine makers derived from lubrication challenges in the top ring groove area.

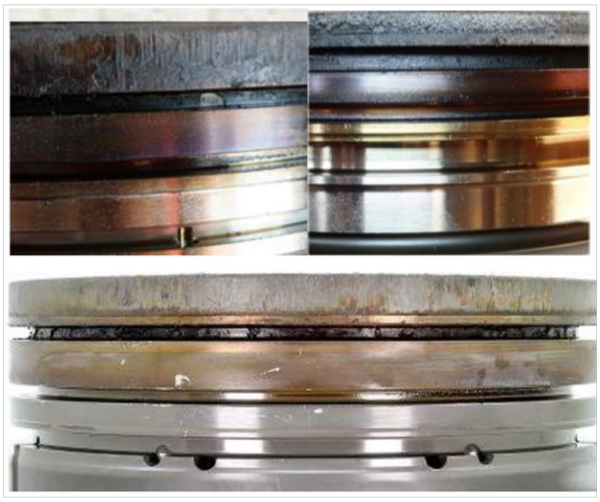

Figure 3. Deposit build-up observations on steel pistons in top ring groove area in 22 bar BMEP engine designs from three different engine makers.

The authors have previously discussed that deposit build up phenomena in the upper part of the piston assembly in high BMEP engines can't be attributed only to thermal cracking of the lubricant; higher lubricant oxidation rates (exacerbated by higher operating temperatures and oxygen partial pressures) and the possible catalytic effect of piston material can have a significant impact on oil degradation with deposit formation as consequence [3].

4. INFLUENCE OF OIL AGEING ON LUBRICATING OIL CLEANING FUNCTION

Modern power generating gas engines operate, by design, with low lubricant consumption rates, often around or below 0.1 g/kWh and ideally at sustained engine loads close to 100%. From an oil stress perspective [1] this means the lubricant in service will experience longer residence time and be exposed to more combustion gases at critical areas in comparison to engines that have higher oil consumptions or that operate a lower engine load or lower BMEP.

At the hottest parts in the piston assembly, particularly the top ring groove area, extended oil residence time will inevitably accelerate oil ageing (thermal breakdown and oxidation) and aged oil has a reduced ability to prevent accumulation (e.g. protecting itself from further degradation) or remove or clean deposits gathered in these areas [3]. For modern gas engines, this has become one of the main drivers behind establishing oil life condemning limits around indicators of oil ageing such as Oxidation (DIN51453) and/or TAN (ASTM D664). From this perspective, oils that resist better thermos-oxidative degradation can have longer service intervals and shall also cope better controlling deposit build up.

5. FIELD EXPERIENCE IN DEPOSIT BUILD-UP WITH PREVIOUS GAS ENGINE OIL GENERATION

In recent years, Shell has gathered significant experience in several steel piston engine designs with several mineral oil based commercial gas engine oils, differences in oil ageing rates (oxidation, alkalinity depletion) and deposit build up observations have been well documented. For instance, low ash engine oils blended in API group II base oils exhibit higher resistance towards oil ageing compared to those blended in API group I base oils, in the contrary, experience with group I base oil products has been generally better in terms of deposit build up observations (when similar condemning limits in oil analysis are applied to oils in service). Figure 4 presents impressions of piston deposits in the same engine design for a commercial oil blended in group II base oil and a commercial product blended in group I base oil after similar engine running hours.

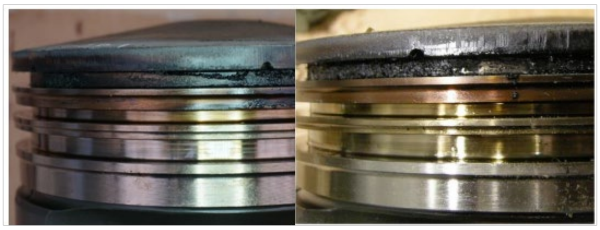

Figure 4. Impressions of piston deposits in J6F engines for a commercial oil blended in API group I base oil (left) and a commercial product blended in group II base oil (right) after similar engine running hours. Oil charge has been changed at least twice as frequently with the API group I base oil lubricant.

It is generally recognized that due to higher unsaturated and aromatic compounds, group I base oils are more polar and can provide higher solvency to polar molecules (as oxidized hydrocarbons) than group II or higher group mineral base oils. This base oil feature appears to be advantageous for deposit control, as it prevents the excessive accumulation of insoluble material formed during oil degradation. However, lubricants formulated in group I base oils generally exhibit shorter oil service intervals as they reach analytical condemning limits more quickly, such as high oxidation values or low alkalinity reserve, amongst others. This makes these oils less attractive to operators since frequent oil changes equal downtime and likely higher lubrication costs due to frequent lubricant renewal, impacting negatively total cost of operation.

In the field, despite higher resistance to oil ageing, former generations of API group II and higher mineral base oil group lubricants have shown more tendency to deposit build up compared to those formulated in API group I base oil. As in the investigation of piston deposits previously reported [3], it is thought that oxidized lubricant molecules are an important contributor to deposit build up in gas engine applications. According to Pawlak et al., once oxidized molecules are present, they can turn from soluble and dispersed species to insoluble material that can end up as deposits [5].

We have also studied the differences observed in the field amongst a few commercial oils through a series of laboratory screeners and a laboratory engine test [3]. It has been possible to correlate deposit build up performance through those tests and these tests were also used to develop new lubricant formulations blended in mineral base oils.

Figure 5 presents the results for the evaluation of top ring area in the single-cylinder screener for the high performing commercial reference oils (API Group I and II based lubricants) and Shell's latest developed oil Shell Mysella S7 N Ultra 40 in terms of carbon deposits, evaluation was done applying methodology described in the ASTM Deposit Rating Manual (formerly CRC).

More detailed background information for this test regarding the advanced lubricant for modern gas engines is already published in the CIMAC Paper No 309 from Congress 2019 in Vancouver [3].

Shell Mysella S7 N Ultra 40 has undergone extensive field testing with various OEMs and proven improved performance in ageing resistance and deposit control compared to previous generation of engine oils.

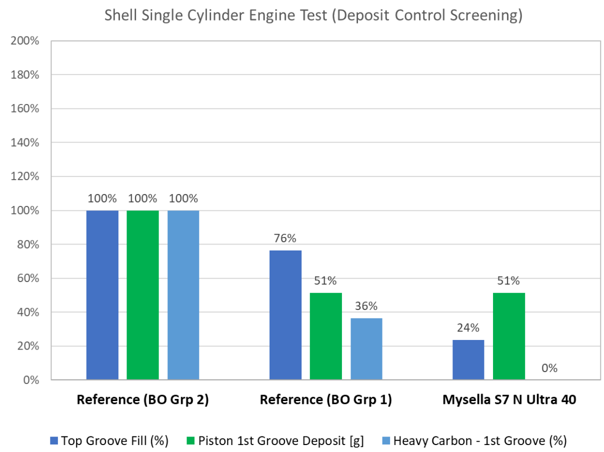

Figure 5. Top groove and top ring evaluation results in a proprietary single cylinder engine test procedure for deposit control screening. Lower scores indicate better performance in deposit control.

6. FIELD PERFORMANCE OF AN ADVANCED LUBRICANT (SHELL MYSELLA S7 N ULTRA 40) FOR MODERN GAS ENGINES

Understanding thermo-oxidative degradation of selected commercial gas engine oils and some field-tested prototypes in a series of bench and laboratory engine tests [3] has resulted in the development of Shell's newest advanced gas engine oil, Shell Mysella S7 N Ultra 40. This lubricant was first approved and was commercially introduced early 2020. Our performance monitoring program for this top tier product was started since introduction. By 2024 this lubricant has accumulated more than 2,000,000 service hours across hundreds of highly rated natural gas engines. Figure 6 shows the engine fleet distribution by engine maker (OEM) where this lubricant is currently in use.

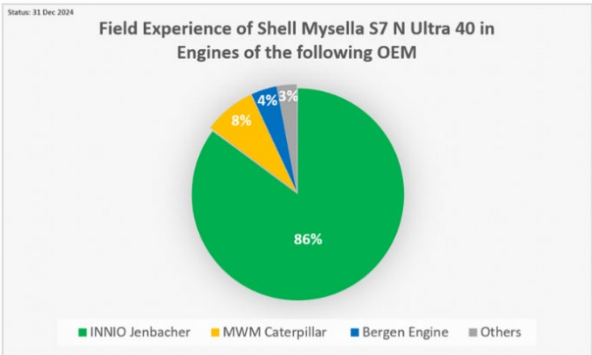

Figure 6. Overview OEM - Field Experience of Shell Mysella S7 N Ultra 40 in Engines.

It is the purpose of this paper to share field experience on selected engine designs with Shell Mysella S7 N Ultra 40:

Field Experience in INNIO Jenbacher Series 6F (Steel Piston – BMEP 22bar)

Based on the Shell Mysella S7 N Ultra 40 monitoring program, figures 6.1 to 6.6 are showing the field performance in INNIO Jenbacher Type 6F natural gas engines. Oil analysist data from almost 100 engines extracted from Shell's LubeAnalyst is included (Status: 31 Dec 2024). The limited factor for an oil drain is here the oxidation. In the oxidation chart (Figure 6.1) the trendline crosses the OEM limit beyond 5000 service hours. The specific lube oil consumption (SLOC) is mainly influenced by the design and the adjustment of the engine. Based on some analysis we have seen an average of 0.18 g/kWh SLOC for J6F natural gas engines. This value can vary in the field.

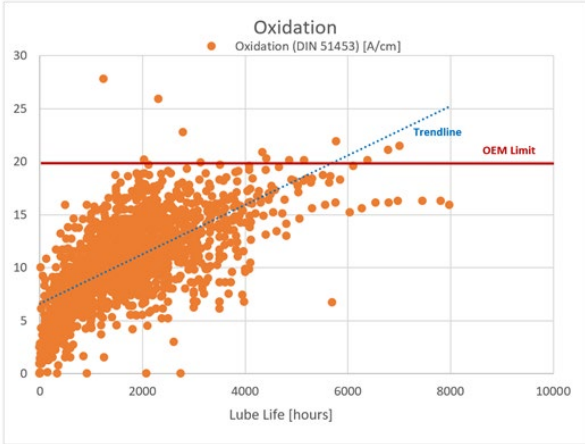

Figure 6.1. Oxidation – Gas Engines INNIO Jenbacher Type 6F – 22bar (Steel Piston)

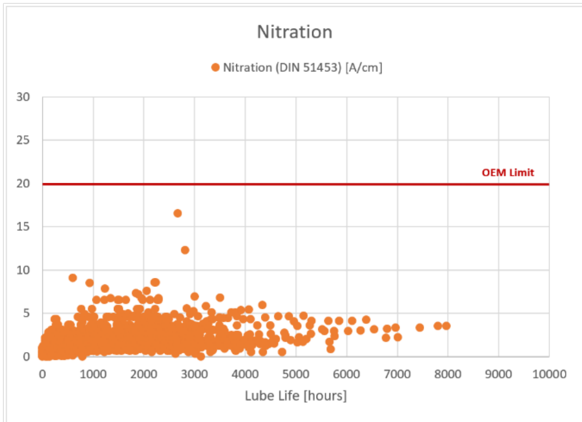

Figure 6.2. Nitration – Gas Engines INNIO Jenbacher Type 6F – 22bar (Steel Piston)

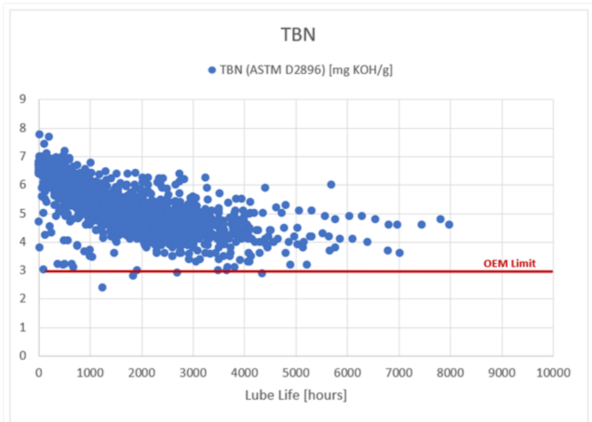

Figure 6.3. TBN – Gas Engines INNIO Jenbacher Type 6F – 22bar (Steel Piston)

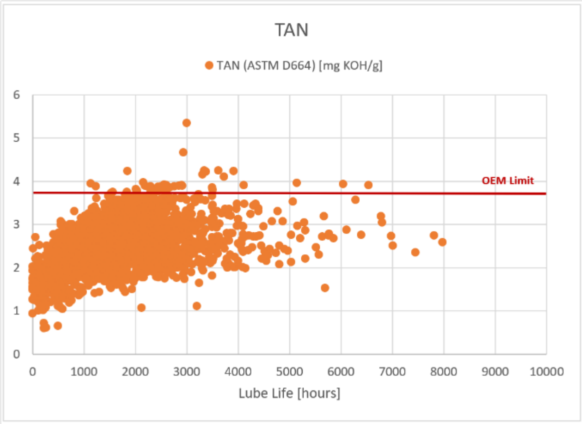

Figure 6.4. TAN – Gas Engines INNIO Jenbacher Type 6F – 22bar (Steel Piston)

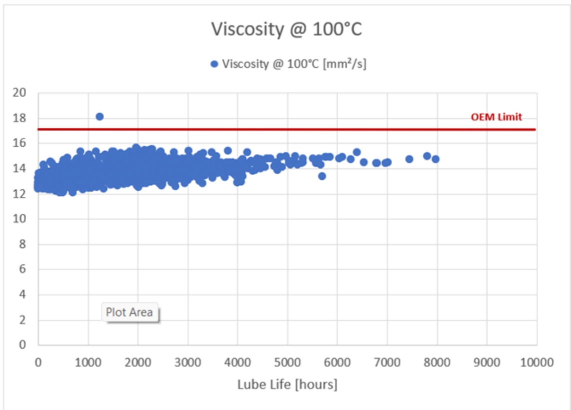

Figure 6.5. Viscosity at 100°C (ASTM D445) – Gas Engines INNIO Jenbacher Type 6F – 22bar (Steel Piston)

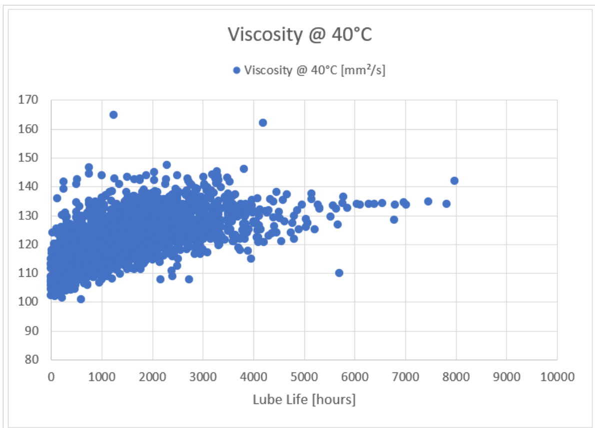

Figure 6.6. Viscosity at 40°C (ASTM D445) – Gas Engines INNIO Jenbacher Type 6F – 22bar (Steel Piston)

Field Experience in INNIO Jenbacher J624 (Steel Piston – BMEP 24bar)

Based on the Shell Mysella S7 N Ultra 40 monitoring program the Figures 6.7 to 6.13 are showing its field performance in INNIO Jenbacher J624 natural gas engines. LubeAnalyst data from more than 50 engines (Status: 31 Dec 2024) in the program are included. The limited factor for an oil drain is here the oxidation. In the oxidation chart (Figure 6.7) the trendline crosses the OEM limit beyond 5000 hours. The specific lube oil consumption (SLOC) is mainly influenced by the design and the adjustment of the engine. Based on some analysis we have seen an average of 0.09 g/kWh SLOC for J624 natural gas engines. This value can vary in the field.

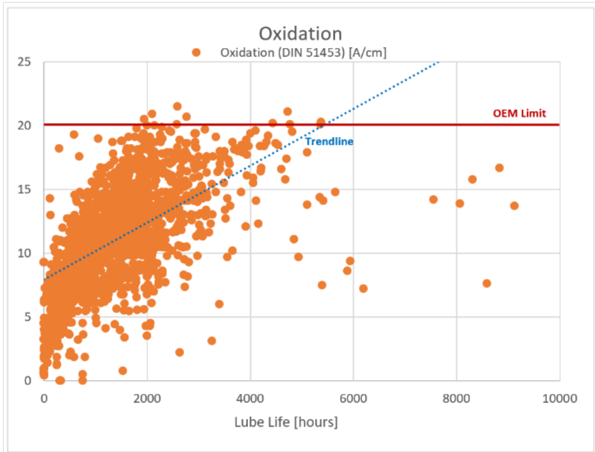

Figure 6.7. Oxidation – Gas Engines INNIO Jenbacher J624 – 24bar (Steel Piston)

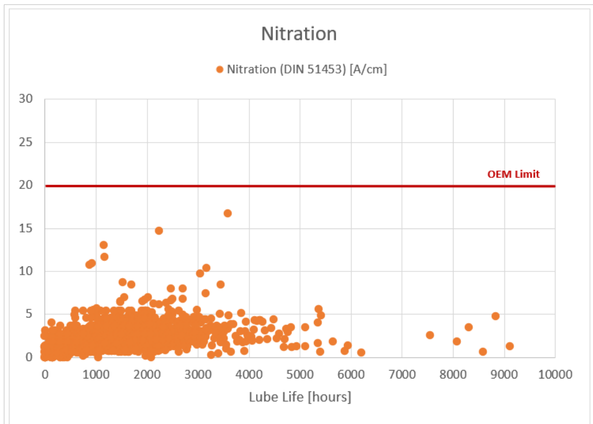

Figure 6.8. Nitration – Gas Engines INNIO Jenbacher J624 – 24bar (Steel Piston)

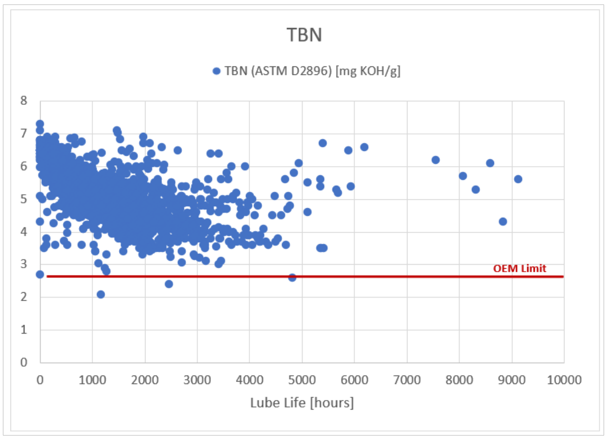

Figure 6.9. TBN – Gas Engines INNIO Jenbacher J624 – 24bar (Steel Piston)

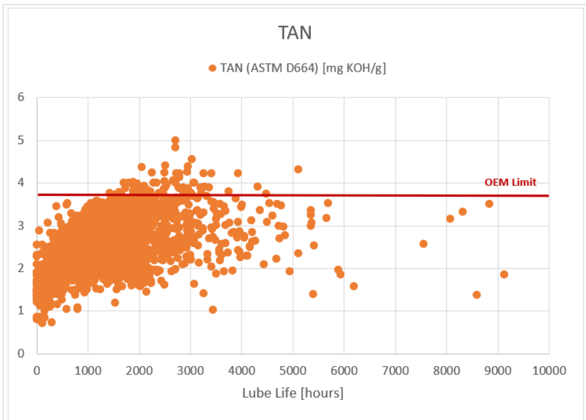

Figure 6.10. TAN – Gas Engines INNIO Jenbacher J624 – 24bar (Steel Piston)

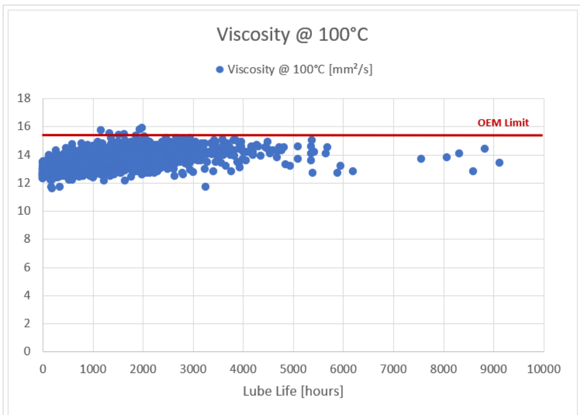

Figure 6.11. Viscosity at 100°C (ASTM D445) – Gas Engines INNIO Jenbacher J624 – 24bar (Steel Piston)

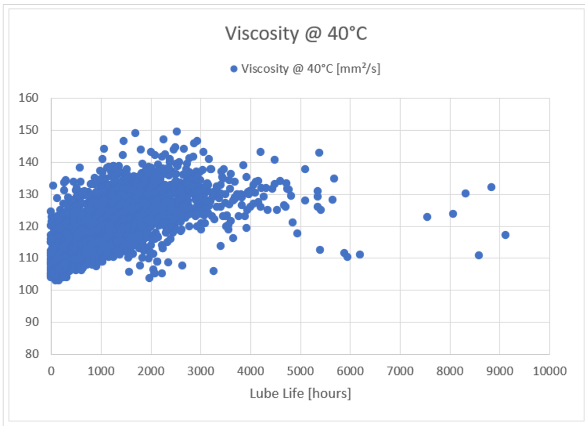

Figure 6.12. Viscosity at 40°C (ASTM D445) – Gas Engines INNIO Jenbacher Series 624 – 24bar (Steel Piston)

Figure 6.13. Inspection of Cylinder Head and Piston show less deposits, and it confirms the high performance of the used Mysella S7 N Ultra 40 in the Gas Engine INNIO Jenbacher J624 – 24bar (Steel Piston).

Field Experience in MWM Caterpillar TCG 20XX/30XX (BMEP 21.5 bar)

Based on the Shell Mysella S7 N Ultra 40 monitoring program the Figures 6.14 to 6.20 are showing its field performance in MWM Caterpillar TCG 20XX/30XX natural gas engines. LubeAnalyst data from 15 engines were included (Status: 31 Dec 2024). The limited factor for an oil drain is here the oxidation. In the oxidation chart (Figure 6.14) the trendline crosses the OEM limit at ca. 5000 service hours. The specific lube oil consumption (SLOC) is mainly influenced by the design and the adjustment of the engine. Based on some analysis we have seen an average of 0.15 g/kWh SLOC for Series TCG 20XX/30XX natural gas engines. This value can vary in the field.

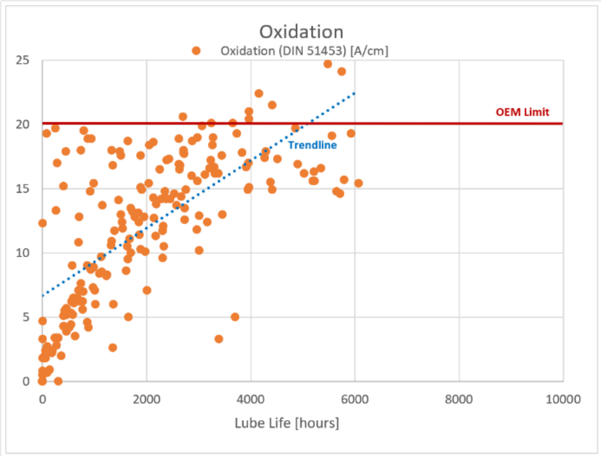

Figure 6.14. Oxidation – Gas Engines MWM Caterpillar TCG 20XX/30XX (BMEP 21.5bar)

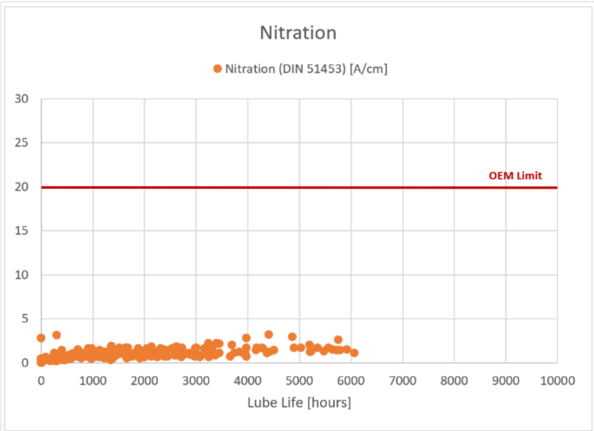

Figure 6.15. Nitration – Gas Engines MWM Caterpillar TCG 20XX/30XX (BMEP 21.5bar)

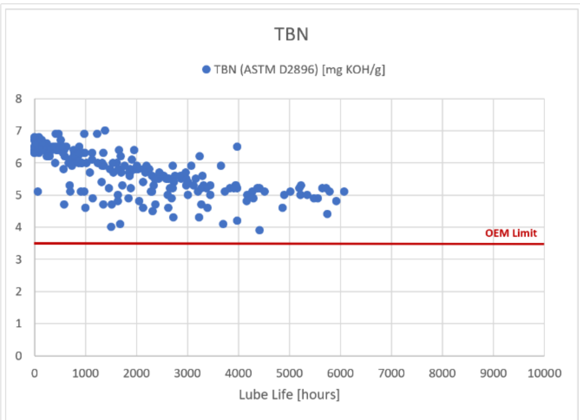

Figure 6.16. TBN – Gas Engines MWM Caterpillar TCG 20XX/30XX (BMEP 21.5bar)

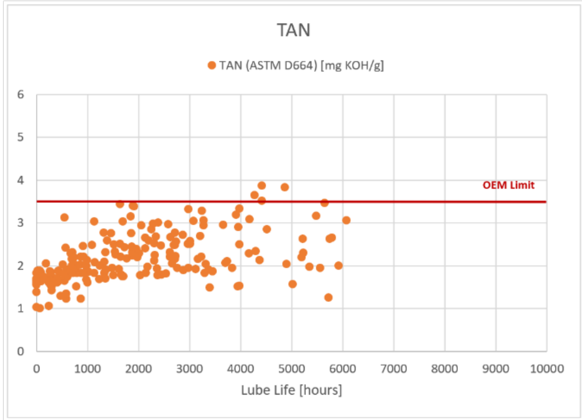

Figure 6.17. TAN – Gas Engines MWM Caterpillar TCG 20XX/30XX (BMEP 21.5bar)

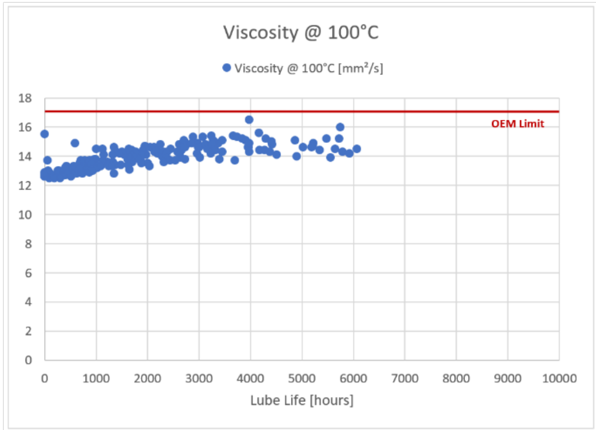

Figure 6.18. Viscosity at 100°C (ASTM D445) – Gas Engines MWM Caterpillar TCG 20XX/30XX (BMEP 21.5bar)

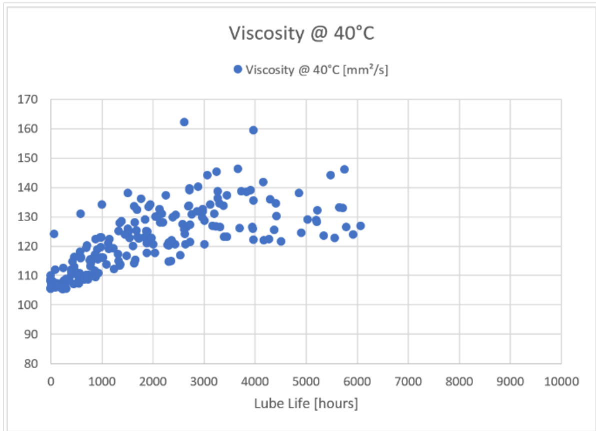

Figure 6.19. Viscosity at 40°C (ASTM D445) – Gas Engines MWM Caterpillar TCG 20XX/30XX (BMEP 21.5bar)

Figure 6.20. Inspection of Cylinder Head, Piston and liner show less deposits and it confirms the high performance of the used Mysella S7 N Ultra 40 in the Gas Engine MWM Caterpillar TCG 2020 V12 (BMEP 21.5bar)

Field Experience with Shell Mysella S5 N 40 (Reference) in INNIO Jenbacher Series 624 (Steel Piston – BMEP 24bar)

During the development program of Shell Mysella S7 N Ultra 40 the premium product Shell Mysella S5 N 40 was used as high reference oil – performance improvements were also demonstrated comparing field oil analysis data in INNIO Jenbacher natural gas engines. The limited factor for Mysella S5 N 40 regarding oil drain was oxidation and as a second step TBN depletion. Figures 6.21 and 6.22 show trendlines cross the OEM condemning limits at ca. 3000 hours for oxidation and TBN depletion. Based on some analysis we have seen an average of 0.09 g/kWh SLOC for Series 624 natural gas engines. This value can also vary in the field. Comparing the trendlines of the reference and of the new Mysella S7 N Ultra 40 we can see a significant performance improvement for the later.

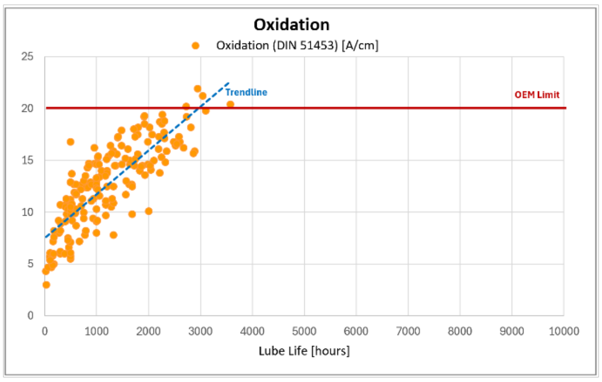

Figure 6.21. Oxidation – Gas Engines INNIO Jenbacher J624 – 24bar (Steel Piston)

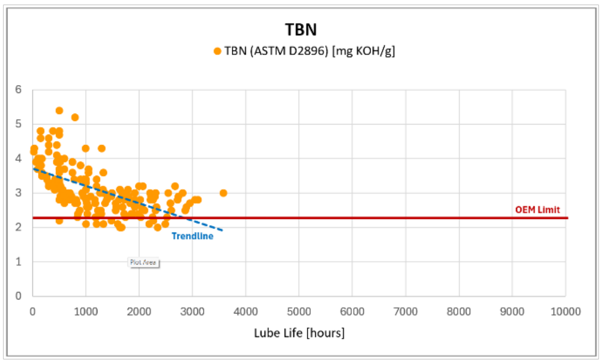

Figure 6.22. TBN – Gas Engines INNIO Jenbacher J624 – 24bar (Steel Piston)

7. CONCLUSIONS

In line with the significant improvements in efficiency and power output of natural gas engines (=> higher BMEP) achieved in the past decade, it was important to develop a new high performing gas engine oil that can assist operators with reducing downtime and maintaining engine reliability. Achieving that longer oil drain intervals can align with engine maintenance activities for other components can have a significant impact in total cost of ownership of a power generation gas engine.

Performance confirmation in the field is essential for broader market adoption/commercial success of a new gas engine oil development, this on top of its first OEM approval trials. For the data analyzed and discussed in this paper, the challenge was to find enough comparable natural gas engines including reference data to confirm the improvement of the performance of the new product.

The database used for this discussion was created out of Shell's LubeAnalyst monitoring system. It delivered sufficient data on service oil analysis for the field performance evaluation. Until end 2024, more than 2 million operation hours with Shell Mysella S7 N Ultra 40 in hundreds of natural gas engines have confirmed that this product is performing in highly rated power generating gas engines. The data clearly demonstrate oil drain intervals have been extended compared to the chosen high performing reference oil.

This new product was especially developed for modern gas engines with high BMEP and often also in combination with steel pistons. Additional these engine types often have a lower SLOC (0.1 g/kWh +/- app. 0.05 g/kWh). With this condition the following engine type selection for the field evaluation was done: 1. INNIO Jenbacher Type 6F 612F/616F/620F (BMEP 22bar); 2. INNIO Jenbacher J624 (BMEP 24bar); 3. MWM Caterpillar TCG 30XX/20XX (BMEP 21.5bar); 4. Shell Mysella S5 N 40 data in INNIO Jenbacher J624 (BMEP 24bar) has been used as reference for the study.

The expected performance of the new product regarding strong increase of a longer oil drain interval and a good deposit control has been confirmed and can be demonstrated via robust evidence with field experience.

8. REFERENCES

[1] Barnes, Foster, Hengeveld, Schasfoort, Scheele. 2004. “Oil Stress Investigations in Shell’s Medium Speed Laboratory Engine”, Paper 21, CIMAC Congress 2004, Kyoto.

[2] Lang J., Schäffert P., Böwing R., Rivellini S., Nota F., Klausner J. (2017) Development of a new generation of GE’s Jenbacher type 6 gas engines. In: Siebenpfeiffer W. (eds) Heavy-Duty-, On- und Off-Highway-Motoren 2016. Proceedings. Springer Vieweg, Wiesbaden.

[3] Garcia, J. and Reher, J. 2019 “Latest Generation of High-Performance Gas Engine Oils – Tackling Reliability Challenges and Extending Oil Life in Modern Highly Efficient Gas Engines”, Paper 309, Pages 3 - 13, CIMAC Congress 2019, Vancouver

[4] Carvalheira, P. and Gonçalves, P. 2006. FEA of Two Engine Pistons Made of Aluminum Cast Alloy A390 and Ductile Iron 65-45-12 Under Service Conditions, 5th International Conference on Mechanics and Materials in Design Porto-Portugal, 24 - 26: 1 - 21.

[5] Pawlak, Z. 2003. Tribochemistry of lubricating oils, Elsevier, UK. Tribology Series 45. Chapter 6.

[6] MWM Product Line Brochures Gas Engines (TCG 2020 Version 04-23/EN, TCG 3020 03-24/EN)