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Part 2

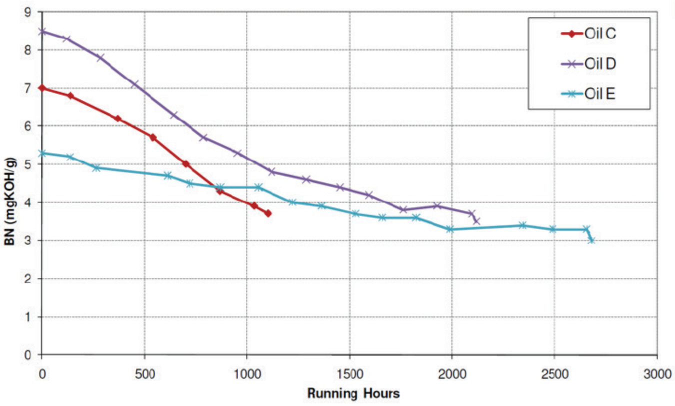

Figure 5. BN depletion trends of three candidate oils.

The chart in figure 5 clearly demonstrates that these three different candidate oils have very different BN depletion rates. Oil C and Oil D consume their BN much faster than Oil E.

Oil C depletes BN so fast that after only 800 running hours the BN is below that of oil E, even if its initial BN was 1.8 points higher than oil E. The BN of oil D does not cross the BN of Oil E, but after 2000 running hours the BN of both oils is almost equal. The chemistries used in Oil C and Oil D, although very different, both provide a less durable type of BN than the chemistry of Oil E.

In figure 6 the BN control limits for the three candidate oils have been entered in the chart, which helps to demonstrate how the different BN depletion rates translate into life. The oil control limit for BN is at 50% of the fresh oil BN.

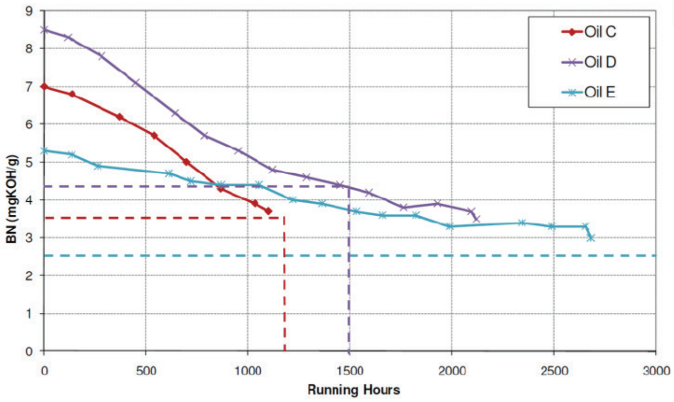

Figure 6. BN limits and achievable oil life for three candidate oils.

This chart demonstrates clearly that the rapid BN depletion of oils C and D results in shorter oil life than oil E, despite their higher initial BN value. With Oil C the oil drain interval has to be set at 1200 running hours only, for Oil D the oil drain interval would have to be set at 1500 hours. Oil E however, despite its relatively low initial BN, has demonstrated to safely reach 2680 running hours, and extrapolation of the oil condition trends predicts that it could safely reach 3000 running hours.

If the BN rejection limit would not have been a function of fresh oil BN, but a fixed number of e.g. 2.0, then also Oil D would have provided a longer life. From a physical and chemical perspective, Oil D can safely run longer than the 1500 hours that is the limit according current operational practice.

5.2. Oil life comparison of candidates with benchmark

The internal benchmark, Shell Mysella S3 S has been used at this site before the candidate oils were tested. There are good statistics available of this oil at this site. A handicap however is that the customer used to change the oil well before it had reached rejection limits. Therefore in order to allow comparison of Shell Mysella S3 S with the candidate oils, the trends had to be extrapolated. The results are as follows:

	Benchmark oil	Oil C	Oil D	Oil E
Actual oil drain interval	800 rh	1100 rh	2120 rh	2650 rh
Achievable oil drain interval	1600 rh	1200 rh	1500 rh	3000 rh

Table 2. Comparison of oil life of benchmark and candidate oils.

Only oil E, despite its low initial BN, provides significantly longer oil life than the benchmark. This is thanks to its high resistance to oxidation, in combination with the relatively mild acidity of the fuel gas. If the fuel gas had a high content of aggressive acidic compounds, then a slow rate of oxidation would not contribute to the extension of oil life. Instead the alkalinity reserve would dominate, i.e. the availability of durable and useful BN. In such case, Shell Mysella S3 S would provide longer oil life than all of the candidate oils, including Oil E, thanks to its higher buffer of durable alkaline additives.

Many OEMs however do not support the use of medium ash oils such as Shell Mysella S3 S, and recommend the use of low ash oil such as Oil E even for aggressive landfill gases. In such cases Oil E is expected to provide longer oil life than traditional low ash oils, because its slow rate of oxidation leaves more BN available for acid neutralization.

To confirm the good results of Oil E and to get more experience the field test was further prolonged with 2 more oil drain intervals (see appendix 2). After running in a kind of equilibrium (more than 5400 running hours with Oil E) the field test was stopped without exceeding any limits.

5.3. Engine condition

For engines running on landfill gas, the condition of components is not only a function of running hours, it is also strongly dependant on fuel characteristics. Acid compounds have been discussed above, and can be reasonably well abated with the help of a good lubricating oil in combination with oil condition monitoring. Another important effect is however the formation of hard deposits as a result of siloxanes in the fuel. Here the influence of the lubricating oil is limited since the deposits are formed directly during the combustion of the fuel with minimal interference of the lubricating oil.

One aspect however where the lubricating oil can contribute, is by minimizing the formation of lubricating oil related deposits, e.g. ash and oil coke.

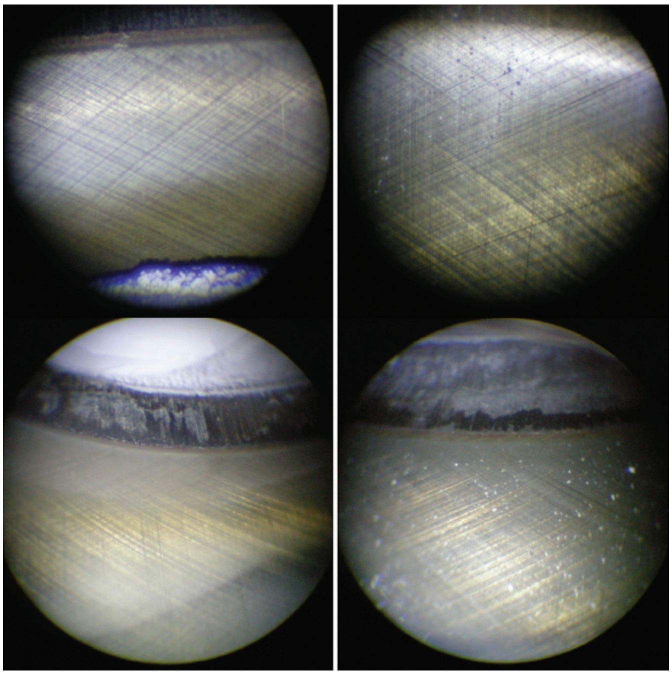

Figure 7. *Condition of cylinder liners 6640 rh after overhaul and 3670 rh with Oil E The inspection shows that liners are in excellent condition with hardly any wear of the honing pattern. In just a few liners, scratches were seen that were caused by hard SiO2 particles. The good condition is also confirmed by the low and stable oil consumption of the engine.*

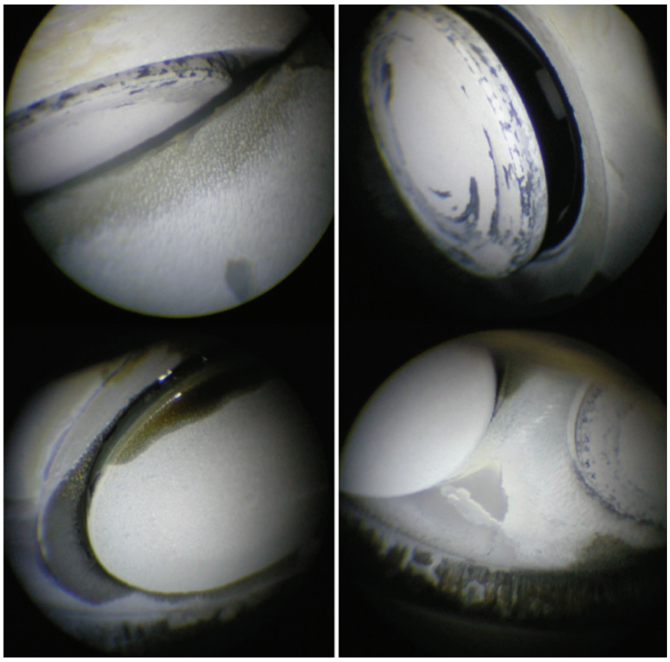

Figure 8. *Condition of cylinder heads after 3670 rh with Oil E Deposits in the combustion chamber were well under control, the ash layers were relatively thin, and no evidence was found of large pieces of solid material broken out of the deposit layer. This has to be judged in correlation with the moderate level of siloxanes in the fuel (ref appendix 1).*

In order to check the performance of the candidate oils, Shell executed boroscopic inspections at the end of the running period on each of the oils tested. The pictures in figures 7, 8 and 9 provide a representative impression of the condition of the combustion chamber after 3670 running hours on Oil E. Cylinder heads had been newly installed just before starting with Oil E, whereas pistons and liners had collected 6640 running hours at the time of this "no harm" type of inspection.

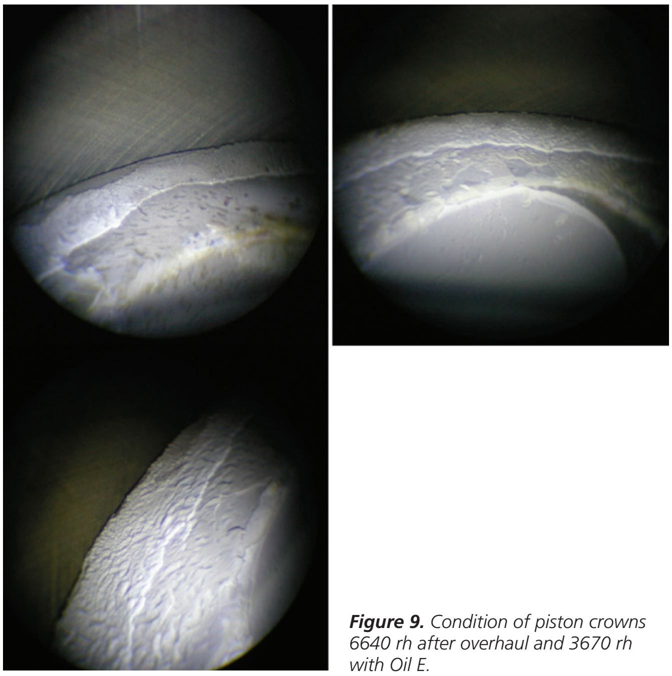

Figure 9. *Condition of piston crowns 6640 rh after overhaul and 3670 rh with Oil E.*

Conclusions

Based on the work presented in this paper, Shell commercialised candidate Oil E and introduced it into the market as Shell Mysella S5 S some months ago. With this product in the portfolio, Shell Lubricants can offer their customers long oil drain intervals in engines running on biogas in the following way:

- By offering Shell Mysella S3 S for installations running on highly acidic fuel gas.

Shell Mysella S3 S provides high acid neutralization capacity through durable BN.

- By offering Shell Mysella S5 S for less acidic biogases, providing very long oil drain intervals thanks to high oxidation resistance and sufficient amount of durable BN.

In addition, Shell Mysella S5S offers good engine protection because:

- It has a low ash content, reducing the contribution of lube oil to combustion chamber deposits.
- It is an advanced additive formulation in Group II base oils, which helps to further minimize ash and carbon deposits.

Field experience- with Shell Mysella S5 S has reconfirmed the potential and the benefits of this lubricant for customers who operate engines on landfill gas, by demonstrating very long oil life and good control of combustion chamber deposits.

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- Peter Busse, Lubricant Development Manager, Shell Global Solutions (Deutschland) GmbH

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2. http://www.hkc22.com/biogas.html
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4. Technical Instruction "Limit levels for used oil in GE Jenbacher gas engines", TI No 1000-0099B, GE-Jenbacher, January 2009
5. Service Bulletin "Cat Gas Engine Lubricant, Fuel and Coolant Recommendations", SEBU 6400-05, Caterpillar, November 2010

Appendix 1:
Field trial installation data

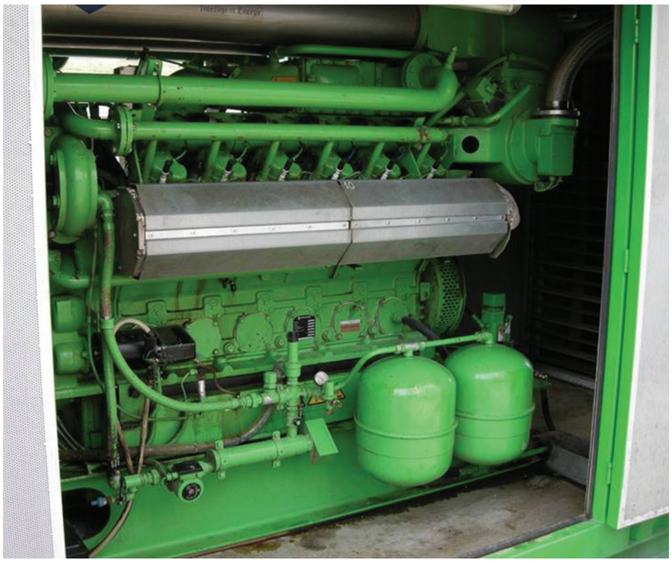
Trial engine:

GE-Jenbacher J312 GSC21 installed on a landfill site in Italy
Engine rating: 646 kWm
Engine speed 1500 rpm
Genset rating: 625 kWe
Actual load: 550 kWe
Oil volume: 320 liter
Oil consumption: 0.12 liter/hr, i.e. 0.18 g/kWh

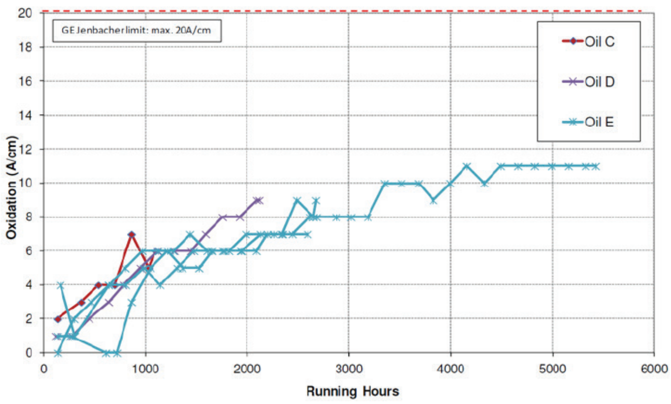
The installation is equipped with:

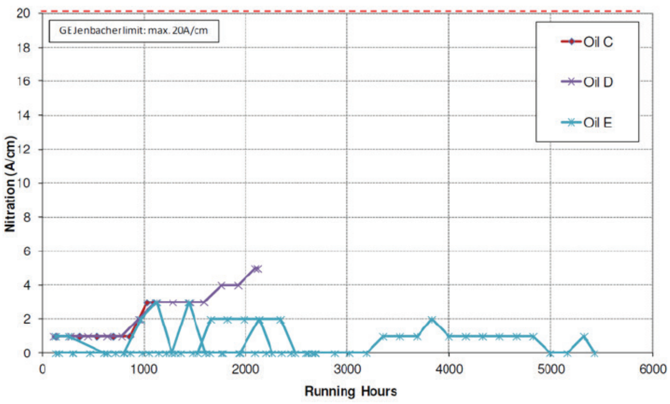
Enlarged oil volume (320 liter)
Oxidation catalyst

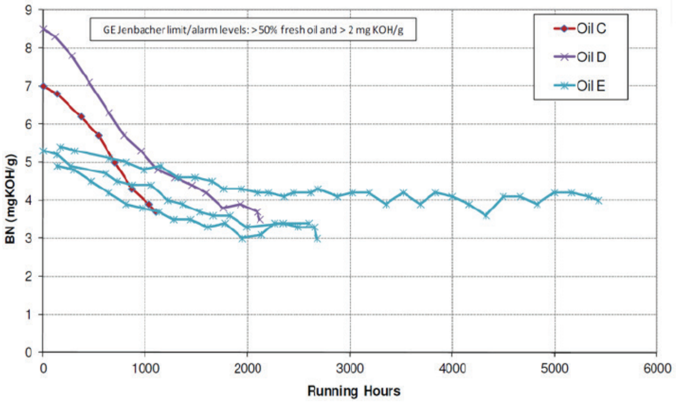
The landfill gas is not cleaned before going into the engine. The fuel gas is relatively mild when considering acids. The Si B value (as per GE-Jenbacher calculation) is 0.04, twice as high as GE-Jenbacher's limit, but in comparison with some other landfill sites, it is still quite moderate.

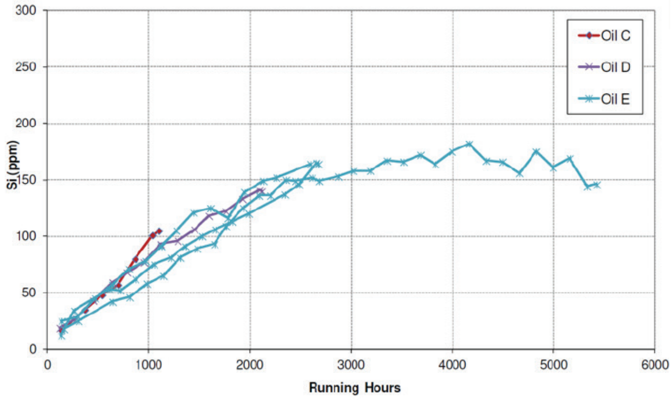


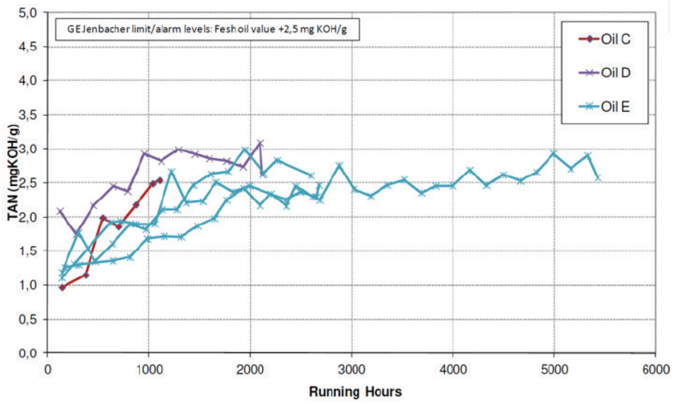
Appendix 2:
Oil analysis results of the field trials of the candidate formulations

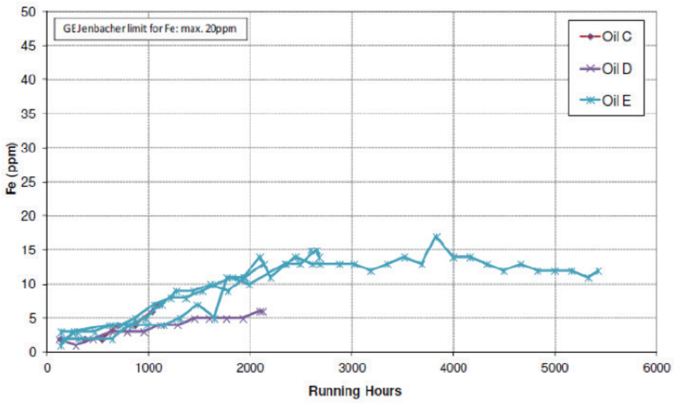


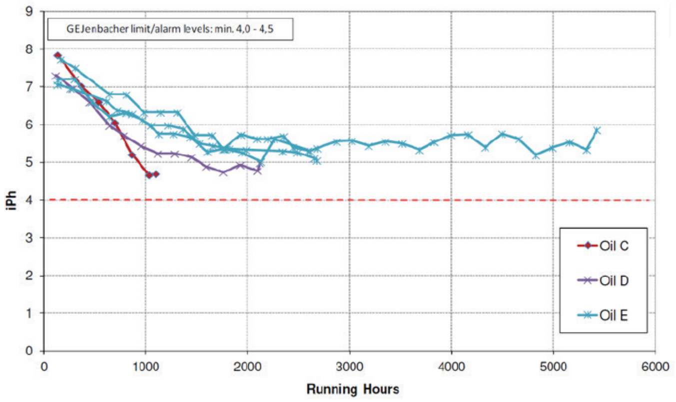












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