Considerations for using low-sulphur fuel

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SUMMARY

When are problems with low sulphur fuel most likely? Sulzer RTA low-speed diesel engine can usually switch from high to low sulphur with no change in piston-running behaviour. However, sudden severe wear is more likely if there is an accumulation of so-called risk factors, such as:

- Low-sulphur fuel
- High cylinder lubricating oil feed rate
- Heavy deposit on the piston crown
- No anti-polishing ring
- High scavenge air humidity
- Poor scavenge air water removal after cooler
- Minimal quality of cylinder lubricant

For example, low sulphur fuel might be used in a temperate region with no problem, but if the ship enters a region with a very high water concentration in the scavenge air, if the water separator and air cooler drainage system are not operating correctly, and if a BN 70 lubricant is used at a feed rate of greater than 1.3 g/kWh, then these cumulative factors will lead to a high risk of sudden severe wear. In other words, if several conditions on the above list are fulfilled, then some action should be taken to reduce the risk.

1 INTRODUCTION

There is increasing public pressure for a reduction in the sulphur oxide (SO_X) emissions from marine diesel engines. Much has been done on land to curtail SO_X emissions and now attention is turning to marine sources. SO_X is the principal cause of “acid rain” affecting trees and damaging buildings. However acid rain has little effect on sea water. Even in the worst affected coastal regions of heavy shipping routes, the marine contribution to SO_X emissions is still less than five percent of that from land based sources[1]. Annex VI of the MARPOL 73/78 imposes a general cap on the sulphur content of all marine bunkers world-wide of 4.5 percent by weight. In addition, the Annex provides for SO_X emission control areas (SECA) to be declared in specific areas of the world, in which the sulphur content of marine fuel is to be less than 1.5 percent by weight. So far, the Baltic, North Sea and English Channel have been declared as SECAs. Although the regulations in the MARPOL annex will only come into force when it has been ratified by an adequate number of maritime countries, it can be expected that the global limit will be lowered further at some time in the future.

Since 1998, Swedish ports have given discounts on port and fairway dues if ship owners can verify that their ships are using bunkers with less than one percent sulphur. Marine fuel has typically a sulphur content of 2.5 to 4.0 percent. In general, residual fuels used in marine diesel engines are only considered to have a low-sulphur content if they have less than one percent sulphur by weight[2].

Low-sulphur fuels have become more frequently used in the run-up to the legislation coming into force. Questions are asked as to whether engines can handle low-sulphur fuel, and what special measures ship owners need to take. Here the matter is covered as it affects in particular Sulzer RTA-series engines. Generally this is not really a problem for four-stroke engines, because lubricant is matched to fuel sulphur content and measures have been implemented to prevent bore polishing.

2 EXPERIENCE WITH LOW-SULPHUR FUEL

Low-sulphur fuel is used on many ships with BN 70 lubricants for a short period, whenever one bunker has by coincidence a low sulphur content. In some ports in South America only low-sulphur fuel is available.

There has been much experience on test bed engines and on older engine types. Modern RTA engines usually have had no problems. To run successfully on low-sulphur fuel we need to find the correct adjustment of operational parameters. These include, for example, ensuring the water separator after the scavenge air cooler is working efficiently, and using an appropriate cylinder lubricant, at the correct feed rate.

The lubricant feed rate is a crucial factor. It is often the only parameter that can be easily adjusted to match the fuel sulphur content. There is unfortunately for historical reasons a lot of resistance to reducing feed. In cases of doubt the feed rate is mostly raised and exactly that can trigger sudden severe wear.

A feed rate which is too high will cause instability in the piston ring pack and increase deposits on the piston top land. If too low, there might not be enough oil to form a stable oil film, or more likely piston ring and cylinder liner wear rates will be high due to corrosion.

For short periods of running on low-sulphur fuel, when only the standard BN 70 cylinder lubricant is available on board, the piston-running behaviour must be carefully monitored. The cylinder lubricant feed rate should be in the range 1.0 to 1.3 g/kWh.

On a good condition cylinder liner, with satisfactory cylinder liner wear rates and at high operational load, the feed rate should not be more than 1.2 g/kWh, and a feed rate closer to 1.0 g/kWh will usually give the best results. Such low feed rates are even possible on engines with no mid-stroke insulation, provided the operational load is high (75 percent and above). The main risk is corrosive wear, if the load is lowered over longer periods.

The feed rate should only be lowered after investigating the wear status of the rings and liners. If the condition appears critical, then there should be no reduction. Cylinder liner wall temperature monitoring is a very useful tool to aid reducing the cylinder lubricant feed rate, as it will give an early warning of piston-running difficulties. Monitoring the iron content of piston underside drain oil at different cylinder lubricant feed rates will provide very valuable information when trying to find the optimum feed rate for a certain set of operating conditions[3].

Wärtsilä is confident that the cylinder oil feed rate can be permanently reduced to about 1.0 g/kWh on engines where the TriboPack design measures have been implemented. TriboPack increases the safety against scuffing by providing the best possible running surfaces. The anti-polishing ring reduces hard coke deposits on the piston top land which destroy the liner's oil film. The complete package provides an additional safety margin for abnormal operating conditions[4]. On some engines a high cylinder lubricant feed rate is required to keep corrosive cylinder liner and piston ring wear under control. With low-sulphur fuel there is less corrosive wear, so it is easier to envisage a reduction in feed rate.

1. Cylinder Lubricant Formulations

2.1 Base Number and detergency

Since the mid 1950s, it has been standard practice to use a cylinder lubricating oil with high alkalinity (in terms of mgKOH/g, expressed as Base Number) when running on heavy fuel oil, in order to neutralise the acidic products of combustion deposited on the surface of the cylinder liner.

With low-sulphur fuel there is less condensed acid to neutralise. A lower BN might seem the logical choice, but it is not so simple. The BN of the cylinder lubricant is an indication of the lubricant's detergent and dispersant properties, and not just its acid neutralisation ability. Detergency and dispersancy are important characteristics of the oil, ensuring a clean ring pack and therefore freely moving piston rings. The lubricant's thermal stability is also linked to the BN additive.

Fig. 1 to 5: Sulzer RTA engine piston top lands at the end of the shop tests, with 0.5 percent sulphur fuel oil[5]. The BN 70 lubricant gives clearly better results than BN 10, as long as the feed rate is not too high.

Fig. 1: BN 10 at 2.9 g/kWh

Fig. 2: BN 10 at 2.2 g/kWh

Fig. 3: BN 70 at 2.1 g/kWh

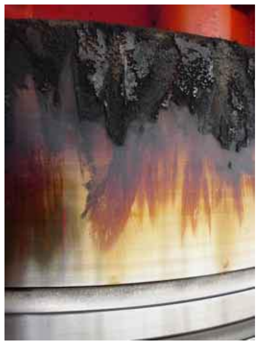

Fig. 4: BN 70 at 2.4 g/kWh

Fig. 5: Close-up view of piston in figure 4 showing that, in just a few running hours, the deposit had built-up sufficiently to contact the liner surface. In this condition there is a high risk of sudden severe wear.

When older formulations of cylinder lubricants with less than BN 30 (mostly BN 12 to 15) have been used with low-sulphur heavy fuel, a heavier contamination of the ring pack has been observed, and liner walls tended to be covered with patches of lacquer, especially in the colder areas. The use of these lubricants is not recommended.

2.2 New cylinder lubricants

A new type of cylinder lubricant with BN 30 to 50, referred to as low BN cylinder lubricant, is coming onto the market in response to demand caused by the move to low-sulphur residual fuel. There is still relatively little experience with these oils under normal service conditions, as few engines run on low-sulphur fuel. The new technology is currently being evaluated on Sulzer engines in service and the Sulzer RTX-3 research engine has been running with a BN 40 lubricant for the past two years.

A good low BN lubricant has hidden detergent properties which are not apparent from the BN. The new lubricants are often reformulations of either BN 70 lubricants, or of medium-speed engine lubricants. A low BN lubricant can either be blended simply by diluting a BN 70 lubricant with base oil, or alternatively by substituting some of the high ash BN additives with other additives that neither contribute significantly to the BN, nor to the ash content. The latter alternative is likely to produce a much better lubricant, but the raw material cost is considerably higher.

Cylinder lubricant for low-speed engines can no longer be satisfactorily characterised by BN. The decisive test is the lubricant's performance in service.

2.3 High or low BN lubricant?

The new class of BN 40 lubricants are better for use with low sulphur fuel than the standard BN 70 lubricants, but often they still are not readily available at short notice. If an engine with a history of piston running difficulties is to run on low-sulphur fuel, then a switch to BN 40 is highly recommended. There will be less top land deposit, because BN 40 forms less ash, and the deposit will be less dangerous, because it will be formed from neutralised BN additives. An increase in corrosive wear can to some extent be avoided by choosing the correct feed rate.

If the ship owner is prepared to keep a variety of different cylinder lubricating oils on board, then these can be used with the corresponding fuel oil. An engine running exclusively on low-sulphur fuel will choose a low BN lubricant formulation.

A lower BN results in less calcium deposit in the turbocharger or the exhaust gas boiler and lower feed rate has a similar effect. Calcium forms the main bulk of this deposit and the calcium content of a lubricant is proportional to its BN.

Even if the TriboPack is fitted it is still of advantage to use a low BN lubricant to reduce deposit formation. The anti-polishing ring prevents top land deposits from causing scuffing, but it is better practice not to form deposits in the first place by using moderate cylinder lubricant feed rates.

2.4 Quality of cylinder lubricants

There has been a tendency to regard the quality of the cylinder lubricant as of minor importance. It was only necessary to have a BN of 70 mgKOH/g, which was sufficient to neutralise the corrosive sulphuric acid. Many modern engines have almost no measurable cylinder liner wear, more so with low-sulphur fuel. In such a situation the acid neutralisation properties of the lubricating oil are less important and the other properties such as detergency and the ability to recover from extreme situations are important, for example extreme local temperatures caused by random direct piston ring to cylinder liner contact.

Scuffing on Sulzer engines is more often initiated at mid-stroke or at reduced load, in regions of the cylinder liner where the wall temperature in normal operation is relatively low, but once scuffing starts a high thermal stability of the cylinder lubricant is essential.

The specific type of additive (sulphonate, phenate, salicylate, etc.) that is used to blend the oil to BN 70 is now known to be important for modern engines. The current general opinion in the industry, borne out by service results on Sulzer engines, is that a balanced blend which will neutralise acid, but which also has a good reserve of thermal stability, will give the best results[6,7,8,9]. The older formulations which were designed primarily to neutralise sulphuric acid do not give the best performance on modern low-speed diesel engines, but they will probably continue to be used on a large number of older engines for a long time to come.

3 Deposits acid and wear

3.1 Piston top land deposits

On engines running on low-sulphur fuel oil with a BN 70 cylinder lubricant, heavy deposits on the piston top land must be avoided. The piston deposits are residue from the thermal degradation of cylinder lubricant. If the deposits are allowed to build up, they will press on the liner running surface over a certain part of the piston stroke. They will then wipe off the lubricating oil film and so allow metal-to-metal contact between the piston rings and liner. A fast increase in load such as occurs at the end of a canal passage is particularly dangerous, because at high load the clearance between piston top land and liner is less and the deposit which filled this gap at low load will press heavily on the liner running surface, when the load is increased.

3.2 Fuel sulphur and sulphuric acid

The most obvious place to look for an explanation for the difference between low sulphur fuel and typical marine residual fuel is the sulphur content itself. The sulphur is burned to SO_2 and SO_3 (sulphur dioxide and trioxide). The SO_3 reacts with water and condenses on the combustion chamber surface as sulphuric acid. The amount and concentration of sulphuric acid depends on both the surface temperature and the relative concentrations of water and SO_3 in the combustion gases. Therefore the effect of either a low sulphur content in the fuel oil, or of a high water content in the combustion gases is similar. Both result in a lower acid concentration. A high scavenge air water concentration occurs regularly when a ship sails in tropical regions.

A cylinder liner which has been running under corrosive conditions has a clear wear profile, with different degrees of wear at different levels. The liner has clearly been subjected to corrosive attack from many different concentrations of sulphuric acid. The corrosive wear depends strongly on the local surface temperature. From this we conclude, amazingly, that sulphur acid almost only acts on the liner surface very close to where it condenses. A reduction in corrosive wear with low-sulphur fuel has been observed in practice, as has a corresponding reduction in the iron concentration of the used cylinder oil.

The top land deposits are not always harmful, but for some reason in combination with low-sulphur fuel there is an increased risk of scuffing[10]. The deposits are different, possibly harder or more solid, when less oil BN additives are neutralised by sulphuric acid.

3.3 Sudden severe wear

To understand what triggers the severe wear with low-sulphur fuel, and makes it "sudden", a comparison with the well-known water carry-over wear mechanism is useful. If the scavenge air water separator is not functioning well, physical contact of water droplets on the oil film and on the ring surfaces destabilises the oil film. This is a well-know mechanism that leads to sudden wear. Similarly, when the top-land deposit, instead of water droplets, removes the oil film from the running surface to a degree where recovery is not possible, sudden severe wear will also occur.

The wear mechanism is mainly abrasive, involving the hard phase material from the liner running surface. This will happen when the hard phase material has been damaged. If there has been no prior damage, then the hard abrasive particles are either released from the liner surface by corrosion or through the mechanical action of the ring on the liner, when not enough lubricant is present. These hard particles cause severe wear.

4 No link to the sulphur content

There are other problems with low-sulphur fuel which are not directly related to the fuel's sulphur content. One high-density low-sulphur crude oil refinery product which is commonly added to marine fuel contains an unusually higher amount of catalyst fines. It has therefore been common for low sulphur fuel to contain high amounts of catalyst fines, often resulting in high cylinder liner wear.

Sometimes low-sulphur fuels contain "exotic" components which dilute the sulphur content, and which should not be present in the fuel (waste automotive lubricants, chemical waste, etc.). Problems occurring while using these fuels are automatically attributed to the actual low sulphur content, which is not correct.

It has been reported that residual fuel with a low sulphur content sometimes has unusual combustion characteristics when ignited in a test rig. However, these results are not relevant for predicting the quality of a fuel for a modern low-speed diesel engine because the combustion temperatures in RTA engines at operational loads are much higher than can possibly be achieved on the test rig.

It has been suggested that the oil film on the running surface is damaged by exposure to the flame of a slow burning fuel by the downward motion of the piston[6,11], but exposure only happens very late in the combustion process and the heat released at this point depends much more strongly on the load than on the type of fuel used. In fact, during this late phase, the combustion occurs in a turbulent diffusion flame, where the rate determining step is the mixing of fuel and oxygen and hence, the chemistry of the fuel has no significant effect.

Furthermore, the existence of such a "long flame" effect would manifest itself in hot corrosion or cracking of the liner and cylinder cover, high exhaust gas temperatures and poor fuel consumption; however, none of these effects has ever been reported in relation to low-sulphur fuel. Computer simulation of flame development during the combustion stroke also shows no likelihood of the oil film on the running surface being burnt off.

5 Conclusion

Sulzer low-speed engines are well placed for using low-sulphur fuel. The correct choice of cylinder lubricant is important, as is setting up the engine according to the Wärtsilä's recommendations, in particular as given in our latest Service Bulletins.

6 References

1. R. Holtbecker, "Emissions Technology Sulzer RTA engines", Wärtsilä Corporation, 1998
2. CIMAC Guidelines 18, 2000
3. F. Chew, CIMAC 2001
4. R. Demmerle, CIMAC 2001
5. M. Berchtold, unpublished, 2001
6. C. Schenk, ISME 2000
7. T. Friesen, CIMAC 2001
8. K. Lim, CIMAC 2001
9. S. Cook, CIMAC 2001
10. K. Aeberli, "Marine News", 3-1999, Wärtsilä Corporation
11. D. Golothan, Proc. IMAS, 1976