Results of the Analysis of the Effects of Low-sulphur Fuel Oil on the Operation of the Marine Two-stroke Slow-speed Diesel Engine

RATKO BOZIC
Univesity of Zadar, Croatia
ZANA BOZIC BRKIC, mag.ing.
Open University POU Bozic, Split, Croatia
Msc. BOZIC SANDRO
Ship Managment Ltd Split,Croatia

Abstract: - The impurities in marine fuels are often directly related to exhaust gas emissions . In the exhaust gas emissions an inevitable result of using heavy fuel oil (HFO) is high level of sulphur oxides (SOx) and nitrogen oxides (NOx).a . The requirements introduced in some shipping for reducing SOx emissions from the marine two-stroke slow-speed diesel engines areas have resulted in using low-sulphur fuel oils in diesel engine operation. The use of the HFO with high sulphur contents has become unacceptable after the regulations brought by Annex VI of the International Convention for the Prevention of Pollution from Ships (MARPOL 73/78), marking some seas as particularly sensitive areas (Emission Control Areas – ECA) and the implementation of the ship exhaust emissions in the ECAs. In the European ECAs maximum allowed fuel sulphur content in amounts to 0.1 % for ships in ports and all inland waterways across the European Union, whereas California Air Resources Board (CARB) applies the regulation limiting the sulphur content in fuel to 0.1 % within 24 NM off the California's shoreline [1], [10], [13]. This paper discusses the results produced by the analysis of the problems occurring when using low sulphur fuel oils in the operation of marine two-stroke slow-speed diesel engines. The paper analyses the effects of the low sulphur fuel on the fuel injection system, fuel combustion and liner lubrication, as well as which measures need to be taken to prevent possible damage to engine components [1], [12], [13].

Key-Words: - low-sulphur fuel, combustion, lubrication, cylinder liner, viscosity.

1 Introduction

Following a series of issues that affected ships due to fuel switching after the introduction of regulations on using low-sulphur fuel oils within 24 miles off the Californian coastline, at request of California Air Resources Board (CARB) a research was conducted from 2009 to 2010, according to [3]. The results of the research showed that the change in fuel causes:

- Loss of propulsion and operation instability as the engine speed was reduced to dead slow or slow astern, resulting in rpm fluctuations or stopping the engine, whereas the engine operation was stable at higher rpm.
- Difficulties in starting the engine or inability to start the engine due to low pressures in fuel systems, low viscosity of fuel, problems related to high-pressure fuel pump operation, fuel injection, leakage of oil in the fuel injectors and sealing rings.
- impossibility reaching maximum speed, inability to reverse the engine ahead/astern, most commonly due to low pressure of fuel injection or malfunctions in injection timing.

Based on spotting difficulties in the California area, American Petroleum Institute (API) published *Technical Considerations of Fuel Switching Practices* in 2009. According to this study, possible in which possible causes are identified in the following events, according to [3]:

- Temperature of fuel during fuel switching causes sticking of the components of high-pressure fuel pumps and injectors due to thermal shock, increase in fuel viscosity and reduced lubrication of high-pressure fuel pumps.
- Non-compliance of the fuel in use and changes caused by scuffing and sticking of high-pressure pumps and fuel injectors.
- Use of inadequate oil for the lubrication of bearings and cylinder liners resulting in excessive wear of the liner and piston rings.

- Liner lacquering as a result of poor lubricating oil film.

2 Results of the analysis of the effects of low-sulphur fuel oil on the operation of the marine two-stroke slow-speed diesel engine

2.1 Problems related to the high-pressure fuel pumps

Since sulphur has lubricating ability, the use of low sulphur fuel oil (LSFO) leads to concern that lubrication of fuel pumps may be inadequate. The viscosity during fuel injection may change from that of heavy fuel oil (HFO) (10-20 mm^2/s) to that of marine gas oil (MGO) (1-3 mm^2/s), and become an issue. Although the lubricating ability of marine fuel oil and sticking of fuel pump require particular attention, the problems are not insurmountable. The engine manufacturers have tested the use of fuel with agents added for enhancing lubricating oil during trials, according to [1], [5], [10].

When the engine is switched from heated heavy fuel oil (HFO) to unheated marine gas oil (MGO) or marine diesel oil (MDO), malfunctions in the high-pressure fuel pump may occur due to vaporisation of the fuel oil because of heat. In addition, the high-pressure fuel pump may leak, i.e. fuel with HFO specifications may end up in the oil sump tank as the engine operates in MGO mode. According to [1], this may have the following effects:

- Decreased viscosity of lubricating oil which, in severe cases, may adversely affect the lubrication of bearings.
- Drop in flash point, which may trigger an explosion in the crankcase.
- Since this fuel has low aromatic properties, it is not compatible with some kinds of rubber, and is likely to cause problems such as inadequate sealing.

Leakage of oil from the high-pressure fuel pump may have the following effects:

- Drop in fuel pump pressure.
- Reduced amount of the fuel injected.
- Poor fuel atomisation.
- Various ignition delays on engines complying with emission regulations such as NOx regulations.

2.2 Combustion problems when using LSFO

Combustion problems may occur due to any the factors listed below, but in most cases, they occur as a combination of several of these factors:

- Low sulphur level,
- Matching of low-sulphur content of fuel oil and the cylinder oil base number (BN),
- FCC catalytic fines,
- Poor combustibility of fuel oil,
- Contamination by used lubricating oil (ULO),
- Design of engine,
- Maintenance and operation of engine.

Although abnormal wear of piston rings and cylinder liners (scuffing) as well as combustion problems such as high temperature corrosion and the use of low sulphur heavy fuel oil (LSHFO) have been observed and addressed for a long time, comprehensive solutions related to the effects of sulphur content in fuel on the combustion process have not yet been found, according to [1], [8], [10].

Some relevant studies can be found in [18] and [19].

2.3 Problem of liner lacquering when using low-sulphur fuel oil

Lacquering is a colouring effect due to black fuel oil without any effect of wear at places where the quantity of lubricating oil is normal. Since anti-polishing rings began to be used in 1990s, the oxides of the piston crown and unburnt oil have been prevented from rubbing against the cylinder liner, and the colouring effect has reduced considerably.

The problem of liner lacquering is a cause for concern when using low-sulphur fuel oil (LSFO) as it is harder to maintain the necessary lubricating oil film across the surface of the liner. This may lead to increased oil consumption. However, the process of lacquering ceases when the engine is switched back to HFO. The use of high-quality lubricating oil with improved thermal stability at high temperatures reduces the effects of fuel and the effects of flame on the cylinder liner surface, according to [1], [6].

2.4 Scuffing effects

Scuffing, which is the cause of abnormal wear of the cylinder liner and piston rings, occurs in a relatively short time, it is a phenomenon that has its own symptoms and can be predict by observing its symptoms. Before scuffing occurs, the lubricating oil film of the cylinder liner starts to break and to form again repetitively. Broken lube oil film allows metal-to-metal contact between the liner wall and piston rings, resulting in friction and increased temperature [1], [11], [10]. The observed and recorded oscillation has a saw-toothed waveform. When this typical phenomenon is detected and if immediate measures such as reducing the engine load or increasing the lubricating oil quantity are taken, then the process can be postponed or prevented. In addition to temperature monitoring, the occurrence of scuffing is prevented by the newly-developed systems that emit alarm when a waveform indicates the above symptoms, according to [1].

It has been established that the damage occurs due to common factors, such as poor performance of the lubricating oil, fuel oil characteristics, torque change, adverse sea conditions, poor engine maintenance, poor choice of material, etc. The trouble is that the scuffing phenomenon occurs fast, it cannot be always accurately predicted, and the ship operator is forced to bear the costs of repair and delay.

Over the last decades, the marine low-speed two-stroke diesel engines have become more powerful and more complex. At the same time, the maintenance intervals have become longer and the maintenance quality lower. On the other hand, the shipping schedules are getting busier, the ship exploitation is maximised and the time spent in port is reduced to minimum. Under the conditions, the shippers and ship operators pay greater attention to the reliability of the vessel, its systems and components. The cylinder liner is one of the essential components of the marine two-stroke slow-speed prime mover and its excessive wear is one of the worst threats a ship operator may address. Inability to operate a ship results in various costs and loss of credibility and image on the market, according to [1].

Excessive wear of the cylinder liner in the ring belt presents a serious problem, according to [1], [11]. It is likely to occur when using low-sulphur fuel oil together with the cylinder lubricating oil having the base number 70 or higher. These oils contain excessive calcium carbonate, i.e. its content is much higher than necessary to neutralize sulphuric acid that is created during fuel combustion. Calcium carbonate settles on the piston ring lands, scraping the oil off the liner wall and causing malfunction in the lubricating process, according to [1], [11], [13].

In order to prevent scuffing and damage to the liner and piston rings, it is possible to monitor the temperature as one of the most distinct scuffing symptoms. For instance, the Temperature Monitoring and Alarming System (T-MAS) is a dedicated system that can detect the symptoms of scuffing on the running surface of the cylinder liner in a large marine diesel engine, before the excessive wear takes place. T-MAS detects potential problems by observing the cylinder liner temperature. Under normal conditions, there is enough lubricating oil on the liner surface. As scuffing starts to occur locally, the oil film gets thinner due to metal-to-metal contact, creating a leak for the high temperature exhaust gases. The system senses the temperature and sets off the alarm in the event of excessive temperature or excessive deviations in temperature, according to [1], [11], [13]. T-MAS consists of the temperature sensors, cables, switchboard, hybrid recording device and personal computer. The standard version features two sensors on each cylinder liner. The purpose of measurement is to read the temperatures at the running surface of the liner. The value observed by the thermopile is proportional to the temperature on the cylinder liner surface.

In addition to careful monitoring of the liner temperature, the standard measures for preventing the excessive wear of the liner include the increased supply of cylinder lube oil, lowering the cooling water temperature in the water jacket, and temporary reduction of load on the affected cylinder by adjusting the feed fuel pump, according to [1], [11], [13]. All these measures postpone or prevent scuffing phenomenon efficiently.

3 Measures taken while using low-sulfur fuels

Reducing the engine load is the most effective measure. By reducing the load, the temperature and pressure are reduced inside the cylinder, as well as the penetration of the atomised fuel, thus maintaining the adequate film of lubricating oil between the cylinder liner and piston rings.

The amount of FCC should be reduced as much as possible, to install fuel oil filters with mesh size below 10 microns, and thoroughly clean the fuel oil, according to [1], [2], [4].

Increasing the feed rate of the cylinder oil and lowering the temperature of the cylinder liner cooling water assure better lubrication. In a normal engine room plan, the outlet temperature of jacket cooling water (JCW) can be made around 75°C. This slightly reduces the temperature of the cylinder lubricating oil temperature on the cylinder liner wall surface is slightly reduced and the viscosity increases. Consequently, the strength of the lubricating oil film increases and the film becomes difficult to degrade. A decrease in engine load and an increase in lubricating oil quantity are also included in the measures for reducing heat in the lubricating oil film, which leads to enhanced strength of the lubricating oil film, according to [1], [10], [13].

New cylinder oil feed systems have been developed and adapted in two-stroke diesel engines: Electronically Controlled Lubricating – ECL System, Swirl Injection Principle – SIP, developed by Mitsubishi Heavy Industries Ltd., Pulse Lubricating System – PLS (Wärtsilä) and Alpha Lubricator System (MAN). These systems directly and effectively supply lubricating oil to a wide area of the cylinder liner running surface.
The cylinder oil is supplied effectively in adequate quantity to the required locations, the reliability of the cylinder oil is improved significantly, and the margin until scuffing is increased as well, i.e. its occurrence is postponed. In this case it is necessary to reduce the load or to increase supply of cylinder oil.

Finally, compared to conventional methods, these systems require a significantly smaller amount of lubricating oil. With the adoption of these cylinder oil supply systems, it is very likely that most of the liner and piston ring problems due to the use of LSFO will be resolved soon, according to [1], [13].

4 Conclusion

Changing the fuel for the main engine is a procedure that can affect the safety of navigation, due to malfunction of the engine or interruption of its operation. In areas where exhaust emissions from shipboard installations are controlled, fuel changes must be carried out on both auxiliary engines and steam generators, according to [2], [3].
If the mixture of HFO and LSGO oils lags in the fuel pips, problems caused by sludge, such as filter clogging, fuel pump clogging, etc., are likely to occur, so careful monitoring is required, according to [1].
LSGO has low kinematic viscosity so it is diffused easily when it leaks. Moreover, as its flash point is also low, there is an increased risk of fire. The flash point of fuel oil used on board ships is regulated to a value above 60°C, in compliance with the SOLAS Convention of IMO, but the flash point of a part of LSGO may be less than 60°C.
With regard to the anti-scuffing properties, 70 BN cylinder oils perform better than the low-BN oils. The rate of neutralizing sulphur acids is to the greatest extent affected by additive composition, not the base number. High-performance 40 BN oils can substitute 70 BN oils, provided that sulphuric acid neutralisation does not result in decreased alkalinity. The 40 BN oils outperform all commercial products and could serve as models for future cylinder oils, according to [1], [11], [12], [13].

Analyzing the possible causes of the encountered problems, we came to the conclusion that they were mainly observed from the technological aspect and the requirements of the engine room plant in the procedure of changing the fuel type on board ships.
The causes must be observed from the organizational aspect, both on board and within the company, and often the mistakes of the operator are not taken into account, according to [3], [10], [13].

References:

[1] NK Class, *Guidance for measures to cope with degraded marine heavy fuels*, Version II, Research Institute Nippon Kaiji Kyokai, Japan 2008.
[2] E. Tireli, *Goriva i njihova primjena na brodu*, University of Rijeka, Faculty of Maritime Studies, Rijeka 2005.
[3] A. Zekić, R. Radonja, D. Berenčić, *Promjena goriva na brodu u kontekstu sigurnosti plovidbe*, Naše more 59(5-6), 2012.
[4] ABS, *Fuel Switching Advisory Notice*, American Bureau Survey, Houston 2010.
[5] MAN Diesel & Turbo, *Operation on Low–Sulfur Fuels, MAN B&W Two–Stroke Engines*, Copenhagen 2010.
[6] *Report on application of low sulpfur fuel to marine diesel engine*, Fuel and Lubricant Committee, the Japan Institution of Marine Engineering, Research Report No. 369, 2005.
[7] J. Liddy and K.C. Lim., *Cylinder oil - positioning for the future*, Motorship Amsterdam Congress 2000.
[8] Y. Wakatsuki, *Fears of Low Sulpfur Fuel Oil*, Mitsubishi Heavy Industries, Ltd., Journal of the Japan Institution of Marine Engineering, Vol. 41, No. 1, 2006.
[9] Y. Wakatsuki, K. Watanabe, T. Yamamoto and T. Takaishi, *Relation between Recent Low Grade Fuel and Reliability of Marine Diesel Engines*, ISME Tokyo 2000, Paper No. TS - 66, 23-27 Oct. 2000.
[10] R. Djini, S. Dvornik, J. Dvornik, *Analysis of the effects of low-sulphur fuel oil on marine diesel engines operation*, International Maritime Science Conference, Book of Proceedings, 6th IMSC, April 28th-29th, Solin, Croatia, ISSN 1847-1498, 11-18, 2014.
[11] Y. Wakatsuki, K. Watanabe, T. Yamamoto and T. Takaishi, *T-MAS the detector of scuffing before excessive wear*, Proceedings of the 7th International Symposium on Marine Engineering Tokyo, October 24th to 28th, 2005.
[12] T. Sasaki, T. Moriwaki, T. Noge, S. Shirahama, N. Arimoto, *The differences of commercial*

cylinder oils performances for marine low speed diesel engine between 70BN and 40BN for low sulfur content marine fuel oil, International Council on Combustion engines, CIMAC, paper No.:161, 2005.

[13] J. Dvornik, S. Dvornik, I. Radan, *Analysis of the effects of low-sulfur fuels on the cylinder liner lubrication in the marine low-speed two-stroke diesel engine*, Proceedings of Naše More, 1st International Conference of Maritime Science & Technology, Dubrovnik, Croatia, pp. 103-113, 2019.

[14] S. Saravanan, G. Nagarajan,, S. Anand, and S. Sampath, *Correlation for Thermal NOx Formation in Compression Ignition (CI) Engine Fuelled with Diesel and Biodiesel*, Energy 42 (1), pp. 401-410., 2012.

[15] F. Scappin, S. H. Stefansson, F. Haglind, A. Andreasen and U. Larsen, *Validation of a Zero-Dimensional Model for Prediction of NOx and Engine Performance for Electronically Controlled Marine Two-Stroke Diesel Engines*, Applied Thermal Engineering, 37, pp. 344-352., 2012.

[16] M. Spahni, B. Schumacher, and A. Karamitsos, *Concepts, Testing and First Service Experience with the Generation X-Engines*, WinGD Low-speed Engines Licensees Conference, Interlaken, available, 2015.

[17] R. A. Varbanets, and S. A. Karianskiy, *Analyse of Marine Diesel Engine Performance*, Journal of Polish CIMAC, 7(1), pp. 269 – 296., 2012.

[18] Sayel M. Fayyad, *Controlling Noise and Gas Emissions by a New Design of Diesel Particulate Filters*, WSEAS Transactions on Applied and Theoretical Mechanics, ISSN / E-ISSN: 1991-8747 / 2224-3429, Volume 15, 2020, Art. #10, pp. 69-81.

[19] O. Mohannad Rawashdeh, M. Sayel Fayyad, Ahmad S. Awwad, *Testing Engine Oil Specifications and Properties and its Effects on the Engines Maintenance and Performance*, WSEAS Transactions on Fluid Mechanics, ISSN / E-ISSN: 1790-5087 / 2224-347X, Volume 15, 2020, Art. #14, pp. 140-148.