OPERATIONAL PROBLEMS IN SLOW SPEED DIESEL ENGINES CAUSED BY USE OF POOR QUALITY FUELS WITH HIGH CAT-FINES CONTENT

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Abstract
The article is focused on operational problems occurring in elements of slow speed, crosshead diesel engines such as piston – piston rings – cylinder liner assembly and fuel injection pumps caused by use of poor quality fuels with high content of catalytic fines. There are characterized common contaminants in these fuels with special attention to the most harmful the residual fuel catalytic particles so-called Cat-Fines, specified the maximum limits and described their influence on engine's tribological pairs. Furthermore, this paper considers the operational precautions and treatment of poor quality fuels with elaboration of specific procedures to prevent and reduce the influence of Cat-fines to tribological wear in engine elements and containing issues of condition monitoring of engine elements.

Key words: *diesel engines; tribological wear; residual fuels; catalytic fines.*

INTRODUCTION

Commercial demands towards ship managers to seek the ways to reduce operating costs combined with environmental legislation demands related to the global use of residual fuels and operation of vessels in certain areas called Emission Control Areas (ECA) create certain problems in safe and economical operation of vessels propelled by slow speed engines. Nowadays, reducing the costs of the ship's operation is primarily related to fuel oil consumption and it is achieved by reducing the actual ship's speed to the most economical speed or to so. very or extreme slow steaming. Furthermore, the fact that the reduction of sulphur content in residual fuels is proportional to a higher average amount of harmful catalytic fines (Cat-fines) used as a catalyst in the crude oil refining process, cause that vessels are bunkered with poor quality fuels. According to the reports by Hill (2013) and the author's research Study (2011, 2016), the reduced engine's load conditions and the steadily deteriorating quality of fuel oils, may lead to the possibility of the various operational difficulties. They can include, inter alia, the increased wear of the tribological pairs and their components mostly in the fuel system as described by Bejger al. (2015) and Henderson (2014) and in PRC assembly: piston - rings - cylinder liner as per research Study of author's (2017), McGeary al. (2004) and Satermeister al. (2013) and have decisive influence on their reliability. Therefore, it creates demands on implementation of operational precautions and improvement of efficiency in onboard fuel oil treatment which were the aims of this study. The results have been presented here as elaboration of specific procedures to prevent abnormal wear in elements of slow speed, crosshead diesel engines such as piston – piston rings – cylinder liner assembly and fuel injection pumps and to reduce the influence of use of poor quality residual fuels with high Cat-fines content on these elements by their condition monitoring.

MATERIALS AND METHODS

During normal operation, slow speed engines are supplied by residual fuels with sulphur content below 3.5% (HFO – Heavy Fuel Oil) and in Emission Control Areas (ECA) by low sulphur residual fuels (LSFO – Low Sulphur Fuel Oil). Besides, before entering the ports included in ECA fuel supply must be changed from residual into distillate low sulphur fuels (MGO – Marine Gas Oil) as it was described by authors (2011). The most common contaminants in these fuels are aluminum – silicon compounds and foreign substances or chemical waste, hazardous to the safety of the ship or detrimental to the performance of machinery. The limit values for different fuel grades presented in Marine Fuel Specification by Exxon Mobile Booklet (2016) indicate the minimum quality of fuel as supplied to the ship ensuring good operating results with commercially available fuels within these limits. However, engine's makers are giving with much lower limits for fuels expecting a positive influence on overhaul periods, by improving combustion as it is described in Wartsila Booklet (2007). Besides, as results from various Insurers, Classification Societies and engine maker's reports described by Henderson (2014) and Hill (2013) during last years it was noticed an increase in engine damage due to poor quality of fuels containing catalytic fines, even though the fuels used by engines were within ISO 8217 specification limits and undergoing on board fuel treatment. It has shown that the most harmful contaminants are catalyst particles being the reason in nearly 90% of the cases. The residual fuel catalytic particles so-called Cat-fines are used as catalyst in the crude oil refining process called fluid catalytic cracking (FCC). The left over after this processing are the remnants which main components are formed in the catalysts alumina-silicates – hard ceramic compounds of aluminum and silicon having a diameter of 5-150μm, oval shape and the hardness near to grinding material. As per ISO 8217:2010 the limit for Cat-fines in bunkered fuels is 60mg/kg (ppm) once engine makers recommend that the inorganic particles of size less than 5μm in the fuel supplying to engine should be less than 20mg/kg and that the contents of catalytic fines should be less than 15mg/kg. This implies that the vessel's fuel treatment systems should be able to meet these requirements. According to own study and the results of majority of the fuel samples received and analyzed by DNV Petroleum Services, they were tested allowing Cat-fines max limit at 80mg/kg and the example is shown in fig. 1 where residual fuels bunkered on two occasions had Cat-fines content at the level above of 65mg/kg.

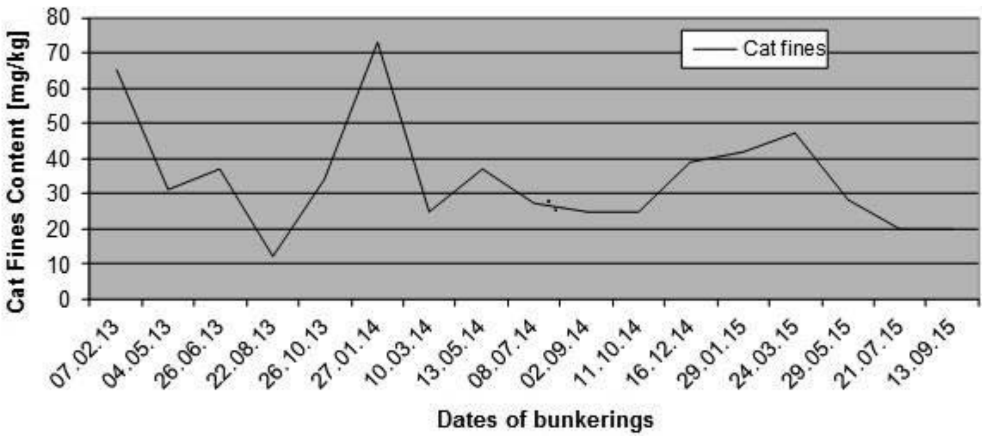

Fig.1 Cat fines content in bunkered residual fuels delivered in Fujairah over two years period of VLCC operation based on DNV Lab results of bunker samples [own study]

Cat-fines damage mainly occurs in large slow speed main engines because the larger fuel injection components allow sizeable Cat-fine particles get into the cylinders where lubricating oil is minimally applied to the liner surface, and doesn't wash them away. The minimum lubricating oil film thickness between the liner surface and piston rings at Top Dead Center (TDC) according to McGeary al. (2004) is down to 0.5μm. Consequently, even very small particles captured between the piston ring and cylinder liner will contribute to the wear in the TDC area. Cat-fines get embedded into engine components and cause abrasive wear to affected PRC assembly: cylinder liners – piston rings (fig. 2a, b) and fuel system: pumps and injectors (fig. 2c, d).As it results from author's research, the appropriate procedures of filtration of fuel oil on board leads to a significant reduction in their content but not to their elimination (6 mg/kg – tab. 1). The remaining in fuel catalytic particles due to their shape and size are not retained even through fine filters with a degree of filtration 10-30μm and still create a risk of increased abrasive wear. During laboratory analysis of worn elements, catalytic particles were found in surface layers of materials, and their average size as per Henderson (2014) was not exceeding 20μm. Generally, larger Cat-fines in the 10-25μm range, are considered most likely to become embedded in the engine parts, however, high amount of cat fines in the 5-10μm range is likely to increase wear rates as well.In compliance with Tier II NOx regulations and Energy Efficiency Design Index (EEDI) guidelines, diesel engines must operate under increased combustion pressures and reduced operating temperatures. These regulations together with poor quality fuels have led to an increase in cold corrosion which is according to elaboration carried out by CIMAC Working Group (2011) the most serious in modern engine designs that have been modified for low-load operation.

a) – abrasive wear of the 1st(upper) ring with visible scuffing wear marks on top and pilled out part of the 2nd(lower) ring. Cat-fines as hard grains causing abrasive wear down to the surface by continuous ploughing and scratching which displays vertical scratches, the size of which depends on the dimensions of the particles involved. These particles can also affect the sides of the rings as they jam in the ring groove, thereby causing "pitting" of the surface.

b) – cold corrosion caused due to the engine operation at “low loads” combined with the increased pressure and reduced temperatures within the engine cylindersthat created conditions below the dew point, allowing water to condense on the cylinder liner walls.That condensate combined with sulphur, forming sulphuric acid – corroding the liner surface and creating excessive wear of the liner material.

c) – solid fuel deposits covering Fuel Injection Pump’s (FIP) spring and plunger. Formation of deposits in FIP parts during engine stoppage due to poor quality fuel comes to deposition and hardened remaining of residual fuel in spring chamber and the lower part of plunger causing precision pair – plunger barrel (BP) is stuck. This leads to difficulties and/ or impossible to start the engine, and therefore require replacement of FIP with stuck parts and/ or its cleaning/ repair.

d) – abrasive wear in FIP plunger with visible scratches caused by fuel with Cat-fines. The presence of Cat-fines between small radial clearances of BP precision pairs causes scratches of running surfaces, difficulties in maintaining of an oil layer between them and leads to accelerated abrasive wear that may cause decrease of maximum combustion pressure, and therefore reduction in indicated power obtained from the cylinder, and even can lead to engine stoppage.

Fig. 2 Abnormal wear in slow speed diesel engine elements caused by poor quality fuels [own study]: a, b – piston rings and cylinder liners (PRC assembly) observed during inspection through scavenge ports; c, d –fuel oil injection pump (FIP) elements condition investigation due to pump’s failure

RESULTS AND DISCUSSION

As presented in the previous chapters, there is a strong need for implementation of operational precautions and improvement of efficiency in onboard fuel oil treatment once consuming poor quality fuels. Based on own research, the authors elaborated the following procedures to prevent/ reduce the influence of Cat-fines to tribological wear of engine’s elements:

Fuel oil storage and distribution on board:

1. Frequent draining of settling and service tanks to remove water and Cat-fines as they have tendency to settle at the bottom. They could be mixed when the sediment is churned up in rough weather and circulate in quantities beyond the capacity of on board fuel treatment plant.

2. Bunker tanks should be stripped as low as possible because new bunkers should preferably be placed to empty tanks, and blending of different fuels avoided. If blending is deemed necessary allowable proportion should be 20:80 and an adequate compatibility test performed.

Fuel oil treatment:

3. The most affective units which can deal with Cat-fines in fuel are purifiers that act as centrifugal force is utilized to accelerate the separation process among elements with different density.
4. If the purifier uses gravity disc (conventional purifiers), it is advisable to select one size larger gravity disc than that recommended by the manufacturer of the purifier. Correct gravity disc, along with steady feed temperature as close as possible to 98°C without fluctuation, determines the position of the oil-water interface (an unstable interface will spoil the efficiency of the plant).
5. Two purifiers should be used in parallel with minimum output and de-sludge at 30 min interval. This will ensure the longest possible retention in the centrifuges and enables optimal efficiency for removal of Cat-fines from very high content of 73 mg/kg to 6 mg/kg with efficiency above 85%. In the contrary, when only one purifier was in use Cat-fines content was reduce to 22 mg/kg – tab. 1.
6. Fuel oil fine and auto backwash filters should be operational and all fuel oil drains should not be reused but incinerated or consumed by auxiliary boiler.

Usage of poor quality fuel

7. The vessel should have sufficient fuel on board to avoid using of newly bunkered fuel without obtaining and acting on the results of fuel sample analysis sent after bunkering.
8. It is recommended that a proper Fuel System Check (FSC) is carried out by taking samples throughout the fuel system at intervals of 4-6 months. However, FSC Samples should also be taken whenever Al/Si as bunkered exceeds 40 mg/kg. Subsequently, the recommendation is to carry out proper testing of samples taken before and after the purifier(s), at the same time. The samples should be sent to accredited laboratories as DNV Petroleum Services for analysis – tab. 1.

Tab. 1 Juxtaposition of Fuel System Check (FSC) results for HFO samples taken before (D) and after purifier (E) for different residual fuels with high Cat-fines content (A) [own elaboration]

Date		Sampling Point	Analysis Results – particles [mg/kg]							
Bunkering	Sampling		Density [kg/m^3]	Water [%]	Sulphur [%]	V	Na	Al.	Si	Cat Fines [mg/kg]
07.02.13		A	989.2	0.06	3.52	54	38	33	32	65
	26.02.13	D	989.4	0.04	3.62	52	32	19	18	37
		E	989.1	0.05	3.63	53	30	11	11	22
27.01.14		A	989.7	0.1	3.41	89	20	34	39	73
	27.02.14	D	989.8	0.07	3.49	92	22	7	7	14
		E	989.8	0.09	3.42	95	22	3	3	6
29.01.15		A	990.5	0.14	3.29	43	21			42
	11.02.15	D	990.4	0.14	3.34	45	21			38
		E	990.9	0.05	3.39	45	11			6

Condition monitoring of engine elements:

9. As far is practical, the condition of cylinder liners and piston rings from scavenge ports should be visually inspected for any abnormalities which were detailed described by authors (2017).
10. Regular engine's performance (combustion pressure measuring) in regular intervals with trend analysis should be measured and analyzed to confirm condition of fuel system.
11. Application of further assessing methods of the condition and wear of PCR during operation of large slow speed engines by collection of cylinder drain oil (CDO) from under piston spaces including the measurement of Fe-content by spot or online methods (fig. 3) that were subject of research study by authors (2017), McGeary (2004) and elaborated by CIMAC (2011).

Regular intervals of testing with trend monitoring allow to control over abrasive wear caused by presence of Cat-fines in fuel indicated by presence of iron wear particles. In addition, a new method enabling to monitor specific levels of both metallic and corroded iron in cylinder oil, may protect and prevent against Cat-fines attack – fig. 3 and lead to diagnosis based on condition monitoring.

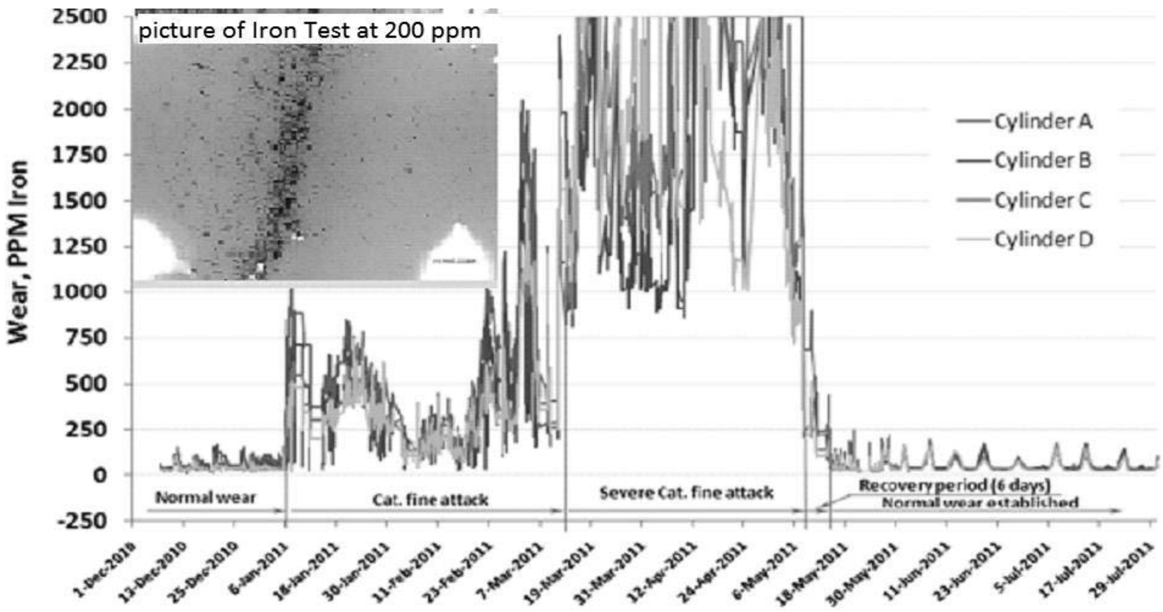

Fig. 3 Severe Cat-fines attack documented by means of Kittiwake online equipment measuring the content of iron wear particles it peaked to more than 2,500 mg/kg [8]. Before attack, the iron level was below 200 mg/kg (Cat-fines alert) as on the picture confirmed by Iron Test [own study]

Knowing the amount of iron in the cylinder scrape down oil related to wear trend in PRC as well as the remaining alkalinity reserve (TBN) – fig.4 is the essential requirement to adjust appropriate cylinder oil feed rate depended also on engine's load and sulphur content in fuel as well and to minimize the impact of the escalating challenge of cold corrosion reported by CIMAC Working Group (2011). The authors' study on interpretation of used oil analysis results and diagnosis of machinery condition, based on precise knowledge of the equipment and experience with operating conditions as the engineering staff on board the vessels backed up by the scientific knowledge and research listed in the author's article giving support from reported incidents and other complimentary information.

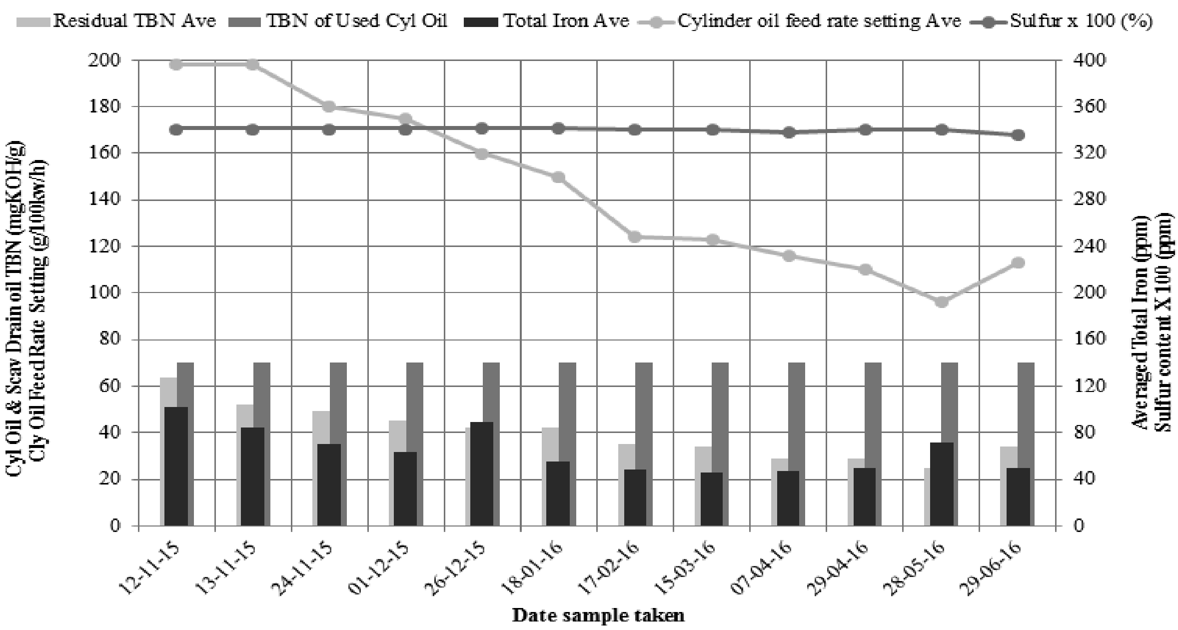

Fig. 4 Relationship of key values (time-series) among cylinder oil feed rate and total iron content in cylinder drain oil in relation to fuel sulphur content and alkalinity reserve [own study]

CONCLUSIONS

The mentioned in this article issues can lead to the following conclusions that can help to understand the core of the problem in operation of slow speed crosshead diesel engines supplied by poor quality fuels with high Cat-fines content, especially once they are running under “low load” condition, minimize cold corrosion appearance and prevent the escalation of engine damages and related both in delays in commercial operations and unnecessary additional costs and insurance claims as well:

- Bunkered poor quality fuels containing Cat-fines impurities even with very small particles are found to be responsible for wear cases in slow speed engines’ tribological nodes such as piston – piston rings – cylinder liner assembly and precision pairs of fuel injection pumps. The problems which arise due to Cat-fines are often unexpected as they are not always evenly distributed in the fuel and are sometimes present even when they do not appear in the analysis results.
- In order to reduce the risk of encountering high wear rates, the Cat-fines content in the bunkered fuel must be reduced significantly by onboard fuel treatment system before entering the engine to meet recommended by engine maker’s limits. The results should be confirmed by checking of Fuel System Check samples in accredited laboratories or implementation of on line analyzers. It should also include engine performance and Iron powder tests by on-site methods with trend monitoring which are not so precise as lab results but are immediate what is very crucial factor in evaluation of each cylinder conditions, combustion and lubrication, confirming which units are functioning correctly and pointing those require attention. The further study will also identify reasons of possible malfunction and help to find the remedy.
- Effective Onboard Fuel Management System could minimize and significantly reduce the risk of engine break-down and lengthy/costly repairs caused by off-spec bunkers if have been implemented and followed at all times. Therefore, ship managers should provide an internal review of their Bunker Handling and Management plans and enhance planned maintenance systems by in order to provide early identification of fuel related problems.

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