Heavy Fuel Oil for Marine Engines - Fuel Additive Option for Quality Improvement

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Introduction

1. The estimated consumption of bunker fuels by the shipping industry globally is over 200 million tonnes per annum.

Projected Scenario for Marine Heavy Fuel Oil Quality Improvement

2. Mr. Martin Suenson of EUROPIA (Europian Petroleum Industry Association) as recorded the following in the context of expectations of improvement in marine engine fuel quality to meet environmental regulations:

2.1. Large scale changes to improve marine fuel quality will require significant changes in refinery, take a long time and entail additional CO2 burden.
2.2. Fuel specification may be set by regulatory bodies but availability and production will be driven by economics. Individual refineries will make individual decisions based on prudent business logic.
2.3. Changes would require large investments in refineries and refinery configuration change can only be gradual and could take 20 to 30 years.
2.4. The cost of improved marine heavy fuels will increase substantially.

Standards - ISO 8217

3.1. Bunker fuel is marketed meeting the standards of ISO 8217 which defines the fuel suitable for use in marine boilers and diesel engines.

Deficiencies:

3.2. The standard includes limits for various fuel characteristics and clauses that control the composition of the fuels. However, it has some deficiencies. This results in use of fuels which meet the requirement of the standard, and yet are not completely fit for engine application. Three such important deficiencies are:
3.2.1. Poor definition and control of fuel stability.
3.2.2. No limits or control on fuel ignition quality.
3.2.3. No limits or controls for injector cleanliness.

Operational Problems:

4. Studies by research groups from oil companies, academic institutions and professional bodies like CIMAC have reported operational problems related to the above deficiencies in fuel quality, which include the following:

5. Fuel Instability:

5.1. Sludge Separation:
5.1.1. Excessive sludge separation in the storage tank & centrifuge and frequent filter choking.

5.1.2. A working group constituted by CIMAC India, based on a survey on 84 marine engine users, reported that a majority of engine operators experienced the problem excessive sludge separation, ranging between 0.5 to 0.1% of the fuel throughput.

5.2. Erraticity in Viscosity Control:

5.2.1. Ineffective viscosity control.

5.2.2. Viscosity is desired to be maintained at about 15 cst at the injector, for optimum fuel atomisation efficiency. A control system measures the viscosity and adjusts the fuel preheat temperature appropriately.

5.2.3. The viscosity measurement instrumentation in the control system is designed to work with a Newtonian liquid.

5.2.4. The presence of the sludge causes the fuel to change from a Newtonian to a non Newtonian fluid.

5.2.5. Non Newtonian liquids result in erratic viscosity measurement and control.

5.3. Rack Jamming:

5.3.1. Irritants in engine operation like frequent rack jamming on account of deposit formation.

5.3.2. Interaction with heavy residual fuel oil based engine users showed that several have often experienced the problem of rack jamming. Rack jamming problems predominantly manifested at start up.

Asphaltene Floc Impact on Fuel Atomisation:

5.4. Fuel instability leads to asphaltene flocculation, which is the major cause of sludge.

5.4.1. Mr. Koen Steernberg, Shell Global Solutions and Mr. Seymour Forget, Shell Marine Products Ltd., UK in their paper "The effects of a changing oil industry on marine fuel quality and how new and old analytical techniques can be used to ensure predictable performance in marine diesel engines" have reported that the asphaltene flocs do not atomise during injection into the combustion chamber, resulting in long burnout times.

5.5. Test Methods for Stability Reserve:

5.5.1. When considering the practical effects of fuel stability, it is not necessary to know the complete chemistry of the fuel. For most applications it is sufficient to know that the fuel is stable and, ideally, has a workable stability reserve.

5.5.2. ISO 8217 only contains the Sediment by Hot Filtration - Potential as a specification parameter for stability. HFT measures sludge in a uel sample. A single test says nothing about the stability of the ample. Only if the Existent is used in conjunction with a repeat test on the sample after it has been treated either thermally or chemically can stability be determined.

5.5.3. The Shell P value method to measure the stability and the reserve stability of the fuel is a more complete method.

5.5.4. One more method which has been standardised is ASTM D 7157 - 05 Standard Test Method for Determination of Intrinsic Stability of Asphaltene-Containing Residues, Heavy Fuel Oils, and Crude Oils ROFA S Value Method)

5.5.4.1. This test method covers a procedure for quantifying the intrinsic stability of the asphaltenes in an oil by an automatic instrument using an optical device.

5.5.4.2. It is applicable to residual products from thermal and hydrocracking processes, providing these products contain 0.5 mass% or greater concentration of asphaltenes.

5.5.4.3. This test method quantifies asphaltene stability in terms of state of peptization of the asphaltenes (S-value), intrinsic stability of the oily medium (So) and the solvency requirements of the peptized asphaltenes (Sa).

5.6.1. A new technique based on the use of an optical scanning device, Turbiscan has been evaluated by Shell.

5.6.2. A correlation was made between the data by Turbiscan and the P-value, a proven technique for determining fuel oil stability reserve.

5.6.3. The Shell study, when comparing the Turbiscan data with the P-value, has recorded that even perfectly stable fuels with P values above 2.0 are classified as unstable according to the Turbiscan method. This led to the conclusion that the Turbiscan test method in its current manifestation does not give a good measure for the fuel oil stability reserve and may erroneously report perfectly stable fuels as unstable or vice-versa.

Exhaust Valve and Turbocharger Deposits

6. Excessive, hard deposits on the exhaust valves and in the turbo charger.

6.1. The working group constituted by IMAC India, based on a survey on 84 marine engine users, reported that a majority of engine operators experienced this problem.

Cause of Deposits - Incomplete Combustion

6.2. The formation of deposits in the combustion chamber, on the exhaust valves and in the turbocharger is diagnosed to be related to a degree of incomplete combustion. Complete and clean combustion is a function of fuel atomisation and fuel ignition quality.

Ignition Quality

CCAI

7.1. The CCAI (Calculated Carbon Aromaticity Index) has been used in the past as a direction indicator of fuel ignition quality.

Fuel Ignition Analyser

7.2. The Fuel Ignition Analyser, Test Method IP 541/06 is now considered a more correctly reflective method to evaluate the ignition quality.

Correlation between CCAI and FIA

7.3. Dr. Harun Ar Rashid of DNV Petroleum Services has recorded based on various studies at DNVP laboratory that fuel ignition quality, as measured by the Fuel Ignition Analyser does not correlated well with CCAI. Therefore CCAI is not reliable tool to project ignition performance in an engine.

Impact of Poor Ignition Quality

7.4. Mr. Atsushi Takeda, Nippon Yuka Kogyo Co. Ltd. Japan & other in their paper "The ignition and the combustion quality by IA (Fuel Ignition Analyzer) of actual MFO and the countermeasure against the MFO with inferior quality" have reported, on the basis of study, investigation and analysis of over 336 samples of residual fuel oil, the following:

> 7.4.1. No strong correlation was found between the general properties and the results of the FIA analysis, except for density and CCAI.
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> 7.4.2. When CCAI was in the area of 845 and above, the dispersion of the ignition delay was large. Thus, CCAI may not always suffice when assessing the ignition and combustion properties of fuel oil.
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> 7.4.3. Moreover, in addition to the relationship between general properties analysis and FIA results, they investigated the relationships with actual cases of combustion problems.

7.5 Poor Ignition Quality of Fuel in All Cases of Performance Problems

> 7.5.1. In all cases of fuel oil causing problems, ignition and combustion quality was lower than for good oil, and the FIA CN (cetane number) was naturally low.
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> 7.5.2. These were concentrated where MD (start of main combustion defined by FIA) was at least 12.4 milli secs and MAT (combustion period defined by FIA) was at least 23 milli secs. The lower the FIA CN was, the greater the ratio in which problems occurred, and FIA CN was concentrated at 20 and under.
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> 7.5.3. A tendency was observed for the occurrence of problems to be concentrated in the region where ROHR (Rate of Heat Release) max. position (the period during which ROHR max. level is reached, defined by FIA) was at least 13 milli secs and ROHR max. level (the point at which ROHR reaches a maximum, defined by FIA) was at most 2.5 bars/milli sec.

Recommended FIA CN Greater Than 20

7.6. Even though a method for evaluating the quality of fuel oil is not yet established, they consider that greater than "FIA CN 20" serves as one criterion for evaluating the quality of ignition and combustion.

Recommended Solutions

7.7. They record that in cases where it is learned that ignition and combustion quality of bunkered fuel oil is inferior, problems may be avoided by:

> 7.7.1. Adjusting the fuel injection timing to appropriate conditions

7.7.2. Improvement of ignition and combustion quality by the use of fuel additives. They confirm that the FIA CN was improved by 1-2 for fuel oil with poor ignition and combustion quality. Therefore, using this additive can prevent actual problems in oil with poor ignition and combustion quality.
7.7.3. Using a mixture of good quality oil with poor ignition quality fuel, stabilised with a stabiliser dispersant additive.

Quality Assurance Programmes

7.8.1. Mr. Koen Steernberg, Shell Global Solutions and Mr. Seymour Forget, Shell Marine Products Ltd., UK in their paper "The effects of a changing oil industry on marine fuel quality and how new and old analytical techniques can be used to ensure predictable performance in marine diesel engines" have also emphasised the importance of Fuel Ignition Quality of the fuel as a parameter for sustained good engine performance.
7.8.2.One oil major has introduced the P-value and FIA in their Fuel Oil Quality Assurance System (FOQAS), where it is part of the fuel oil component approval scheme, and is preparing for the introduction of ignition specifications in production control and product specifications.

Finer Spray Orifices/Higher Cetane Number

7.9.1. Mr. Karl M. Wojick in a presentation at an "International Symposium on "Maritime Power Plant Emissions" has suggested increased cetane number, reduced ignition delay and smaller spray orifices as important for reduced NOx emissions.
7.9.2. The incorporation of a cetane improver in the marine engine residual fuel is a useful medium to address the uncontrolled deficiency of poor ignition quality.

8. Injector Cleanliness

8.1. It is well known and established that over the years changes in refinery processes have been implemented to maximize the yields of distillate products. Catalytic cracking to maximize diesel yields and visbreaking to reduce heavy residual fuel viscosity are changes which have been implemented.

8.2. The process of cracking leads to higher tendency for deposits on injectors arising out of a large presence of cracked unsaturated hydrocarbons.

8.3. In diesel fuel, standards have evolved by engine test methods to measure injector fouling tendency and detergent additive based solutions have been implemented.

8.4. Heavy fuel oil is also rich in cracked streams & unsaturated hydrocarbons which lead to severe injector fouling.

8.5. Interaction with several engine users indicates the standard maintenance practice to inspect injectors every 2000 hours. During such inspection the injection pressure and the spray pattern are checked.

8.6. It has generally been reported that 1/4th of the number of injectors are changed based on the 2000 hour inspection, although the recommended change period is 4000 hours.

8.7. Mr. Karl M. Wojick in a presentation at an "International Symposium on "Maritime Power Plant Emissions" has reported that, for low NOx and and soot emissions, low excess air combustion approaches are targeted.

8.8. Smaller spray holes and higher injection pressures are important for good fuel atomization and turbulence in the spray to achieve lower soot particulate emissions.

8.9. Increased cetane number, reduced ignition delay and smaller spray orifices are important for reduced NOx emissions.

8.10. Finer spray orifices are more prone to be affected even by the slightest amount of injector fouling.

8.11. Therefore injector cleanliness through a well designed detergent chemistry based additive component is an essential fuel quality improvement medium.

Multifunctional Additive Solution

9.1. The deficiencies in fuel quality in respect of stability, ignition quality and injector cleanliness have been studied and established.

9.2. The negative impact of these deficiencies on engine performance covering fuel efficiency, reliable operatability, maintenance and emissions is evident from the range of studies done.

9.3. It is also clear that fuel quality improvement addressing these deficiencies in particular, from the refineries, is unlikely in the short term.

9.4. Logistically it is unavoidable to have wide inconsistencies in fuel quality with fuel sourced from different crudes and different refinery configurations. These constraints also unavoidably allow the fuel quality deficiencies to remain.

9.5. The engine operator has the sustained risk of using a fuel, which, although meeting specifications, is not completely or optimally fit for engine application.

TOTAL Additives & Special Fuels

10. A well researched, comprehensive, ashless (completely organic) Multi Functional Additive addresses the identified deficiencies completely. The additive, EMDFA 401 designed by TOTAL ACS (a wholly owned subsidiary of TOTAL France) addresses all the deficiencies.

10.1. Engine Manufacturers stipulate the condition that the additive must not contain any metallic components, which pose a potential hazard of abrasive wear of the engine. TOTAL EMDFA 401 is a completely organic product which combusts totally with the fuel.

10.2. It improves storage stability to minimise sludge formation in the entire fuel system by an appropriate dispersant component.

- 10.2.1. It ensures elimination of problems of excessive sludge separation and frequent filter choking.
- 10.2.2. It also ensures that fuel remains homogenous and behaves Newtonianlly so that the viscosity control system functions effectively. Precise viscosity control is vital for sustained efficiency of fuel atomisation.

10.3. It contains a detergent dispersant component to ensure sustenance injector cleanliness.

- 10.3.1. This is critical with large proportions of cracked streams in the blended fuel and
- 10.3.2. Use of higher injection pressures and finer orifices for improved engine efficiency and reduced particulate matter emissions.
- 10.3.3. The additive has the effect of clean up of fouled injectors as well as of keeping them clean on a sustained basis with regular use.
- 10.3.4. Sustained and regular use of additive leads to complete combustion and therefore the formation of deposits in the combustion chamber, on the exhaust valve and in the turbo charger are drastically reduced. However if an engine has been operating without an additive there could be deposits formed earlier in the engine and for the existing engine deposits, the additive does not have a curative or clean up effect.
- 10.3.5. Detergency also eliminates rack jamming.

10.4. It contains a cetane improver to address the inadequacy in fuel ignition quality.

Sustained Good Engine Operation

11. Precise viscosity control, sustained injector cleanliness and improvement in self ignition quality of the fuel together contribute to more complete combustion and hence higher fuel efficiency, reduced exhaust valve and turbo charger deposits, lower engine noise and reduced emissions.

12. Land Based Marine Engines in India - Power Generation.

- 12.1.1. Land based marine engines are an important medium of captive power generation in industry in India.
- 12.1.2. B & W Man and Wartsila have are the major suppliers of heavy residual fuel oil based engines in the power sector. However there are several other players like Sulzer, Pielstick, Caterpillar, Deutz, Fuji etc.

12.2. As in the case of the shipping industry, they are also experience problems related to fuels being sourced from different refineries & different crudes and the issues arising out of incompatibility.

Performance Trials

13.1. Performance of the optimally designed multi functional additive was required to be validated by use in live and real operation conditions.

13.2. Land based marine engines used for base load power generation offered an opportunity for evaluation of the benefit with effective monitoring of the data. Accordingly over the past few years, a series of industrial trials have been completed on a variety of engines and the findings of the trials are presented.

13.3. The engines used include Pielstick, Sulzer, Caterpillar, Wartsila and MAN B& W.

13.4. Typical Trial Methodology

13.4.1. 250 hours operation without additive to establish base SFC

13.4.2. 250 hours operation with 1000 ppm clean up dose

13.4.3. 250 hours operation at standard additive dose of 400 ppm to determine SFC with additive and establish performance improvement.

13.4.4. Ensure consistency of load during the trial period to the maximum extent possible. If there are unavoidable load fluctuations eliminate from the reckoning the periods of deviant load.

13.4.5. Trial completion within a 30 to 40 day period thereby assuring reasonable consistency in pre additive and post additive climatic conditions.

14. Dosage

14.1. EMDFA 401 is recommended to be used at a dosage of 400 ppm i.e. 1 litre of additive for 2500 litres of fuel.

14.2. However for an engine where it is believed that injectors are fouled a dosage of 1000 ppm should be used for the first 250 hours of additivation.

15. The benefits consistently derived are

15.1. Improvement in specific fuel consumption which is sustained over a long period. Typical improvement is of the order of 2%.

15.2.1. Long term users have reported significant improvement in maintainability - enhanced life of injectors, exhaust valves and turbocharger components, drastic reduction in exhaust valve and turbo charger deposits, less combustion chamber deposits than observed in the past.
15.2.2. Substantial increase in period between engine overhauls.

15.3.1. Sludge reduction by a factor of 50%, from 1% to less than 0.5%.
15.3.2. Complete elimination of operating irritants like rack jamming and filter choking.

15.4.Reduced emissions.

15.5. Reduced noise.

16. A summary of the benefits observed during the trials is enclosed. The detailed data can be shared only with the consent of the industry where the trial has been done.

Issues During Trials

17. Even in a carefully controlled and monitored trial several issues did arise which often necessitate trial extension and, in some cases, even retrial. These include:

17.1. Changes in fuel quality even from the same source. We have come across instances where the CCAI varied from around 840 at the commencement of the trial to almost 860 towards the end.

17.2. Significant climatic changes during the trial. In one winter trial the pre additive phase was conducted in very clear weather but the additive use phase was characterized by continuous heavy fog. So clearly an apples to apples comparison was not possible.

17.3. Instrument errors. In one instance flow meters required recalibration and the trial repeated on another engine.

Conclusion

18.1. The deterioration in heavy fuel oil quality on account of refinery process changes is an inevitable reality.

18.2. The identification of deficiencies which affects engine performance has been well researched and established by several institutions.

18.3. A comprehensive well designed multi functional additive offers an optimal solution to address these problems.

19. Acknowledgments

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19.3. We also acknowledge the support of Indian Oil Corporation Ltd., Consumer Sales Department responsible for heavy fuel sales, in catalyzing the performance evaluation studies with their heavy fuel oil customers.

19.4. We also acknowledge the support of the service epresentatives of engine manufacturers who, whenever possible, have provided objective views during engine inspections and overhauls.

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