POSSIBLE TRANSITION TO ULTRA LOW SULPHUR DIESEL AS IT RELATES TO LUBRICITY

DIESEL ENGINE COMBUSTION PERFORMANCE AND RELATED DAMAGES, INFLUENCED BY FUEL OIL SULPHUR AND LUBRICATING OIL

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1. POSSIBLE TRANSITION TO ULTRA LOW SULPHUR DIESEL AS IT RELATES TO LUBRICITY

Introduction

Various recent reports have indicated that the inland barging industry represents the most environmental friendly mode of transport. The same reports indicate that the advantage over the road transportation industry however will be reduced significantly in the near future. The causes can be found by the faster development and implementation of cleaner engines and after-treatment equipment e.g. catalyst as well as the facts that the inland barging industry is smaller of scale and engines have a langer life-cycle. At this moment after-treatment technology is ready to be implemented, however the effectiveness of this technology will only be optimized when using a gas oil that contains less than 50 parts per million (ppm) sulphur. Also, the latest generation engines (e.g. CCR II) operate with increased efficiency but have more extreme operating environments. Higher pressures and temperatures make their tolerance for fuel more precise and increases the effects of an “off spec” fuel product.

In order to further reduce the air emissions caused by the inland barging industry, various Dutch organisations representing the inland navigation industry have indicated that when technically possible a swift (inter)national simultanious transition, prior to the time frame indicated by legislature, to Ultra Low Sulphur Diesel (ULSD) would be fully supported. Since lubricating oil plays a crucial role in relation to a transition to ULSD this is briefly covered in chapter 2. The references used for this document are listed in Appendix H.

Scope

In order to assess the possibilities whether the current engines used by inland vessels could possibly operate on ULSD, various research initiatives have taken place or are currently underway. The purpose of this document is to give a better understanding of the possible transition to ULSD as it relates to lubricity as well as to shed light on the current engine combustion performance and related damages, influenced by the current sulphur in the inland vessel fuel oil standards.

Gas oil as it relates to sulphur

In the constantly changing landscape of the ULSD changeover there are a multitude of issues in regards to development and implementation of new systems. In the different instances there has been a similar discussion related to the new ASTM D 975 or EN-590 – Standard Specification for Diesel Fuel Oils as it relates to lubricity for diesel fuel (Appendices E and G).

ULSD (sulphur content: for this document, less than or equal to 15 parts per million) standards as one encounters in fuel standards used by other modes of transport find their origin from the new requirements for diesel engine manufacturers for lower NOx and PM emissions. As a result, new technologies were developed which require a lower sulphur content fuel in order to meet these emission standards. Many of these new systems are based on rotary or distributor type injection pumps which rely on the lubricity of fuel for a reliable operation. Notably, lubricity, the ability of a fuel to provide surface contact lubrication, is crucial to allow for reliable operation. Natural lubricity is provided by trace oxygen and nitrogen containing compounds, certain classes of aromatics and high molecular weight hydrocarbons. Additionally the sulphur itself adds to the lubricity. Increased hydrotreating required to reduce the sulphur levels reduces these naturally occurring factors. Couple this with the better refinement techniques and lower aromatic content of diesel fuel and the natural lubricity suffers greatly. To compensate for the loss of these natural factors, additives are used to replace the lubricity lost. The removal of sulphur from diesel fuel does not just impact the lubricity. Note: A lower sulphur content diesel fuel will not conduct electricity as well, and therefore tend to hold charge.

The lubricating components of the diesel fuel are believed to be the heavier hydrocarbons and polar fuel compounds. Diesel fuel pumps, without an external lubrication system, rely on the lubricating properties of diesel fuel to ensure proper operation. Refining processes to remove sulphur tend to simultaneously reduce diesel fuel components that provide natural lubricity. As diesel fuel sulphur levels decrease, the risk of inadequate lubricity also increases; however, poor lubricity has been observed even in diesel fuels with very high sulphur levels. Inexpensive additives can be used instead of changing the refining process to achieve the desired lubricity level. Inadequate lubricity can result in increased emissions, excessive pump wear and, in some cases, catastrophic failure.

Survey
The current gas oil specification for the inland barging industry has fewer specification criteria compared to the above mentioned ASTM D 975 or EN-590 fuel that is mainly used by the road industry in the United States and Europe. These standards already have compensated for the loss of sulphur by having embedded a minimum lubricity requirement (max. 460 µm - micrometer). These types of fuel have a standard additive put in at refinery level.

The current gas oil for the inland barging industry does not have this type of requirement and therefore it is unknown to what extent this gas oil lubricates.

In order to give more insight into this topic the Shipping Project Bureau (SPB) has collected a total of 12 samples throughout the Netherlands and Germany at random (Appendix A). All samples were tested on the amount of lubricity using the internationally recognized ASTM D 2622 or ISO 20846 method. The samples were also tested on the amount of lubricity according to ISO standard 12156-1.
The test principle is simple, a sample of fluid under test is placed in a test reservoir which is maintained at the specified test temperature. A fixed steel ball is held in a vertically mounted chuck and forced against a horizontally mounted stationary steel plate with an applied load (Figure 1). The test ball is oscillated at a fixed frequency and stroke length while the interface with the plate is fully immersed in the fluid. The corrected wear scar diameter is a measure of the fluid lubricity

Figure 1 - Stationary Steel Plate

When looking at the results one can notice that the amount of sulphur varies between 1110 ppm and 1840 ppm (Appendix B). The amount of sulphur of all samples are below the maximum permissible 2000 ppm. The results also show that the scar diameter varies between 289 and 485 µm. These figures indicate that the lubricity of 11 samples of the current gas oil is slightly better than the minimum requirements described in the EN-590 specification. One exceeds the minimum requirement of 460 µm. In order to give a better understanding of the lubricating factor of EN-590, a total of four samples were taken within the Netherlands and Germany (Appendix C). When one looks at the results of these four samples which were tested according to the same method one will notice that the sulphur is below the maximum permissible level of 10 ppm. Further one will notice that the lubricating factor of this type of fuel is better than of the currently used gas oil with sulphur.

2. DIESEL ENGINE COMBUSTION PERFORMANCE AND RELATED DAMAGES, INFLUENCED BY FUEL OIL AND LUBRICATING OIL

Introduction

An increasing amount of engine malfunctions can be traced back to a poor combustion process. A lot of current inland diesel engine malfunctions which are claimed by their owners, are caused by poor combustion inside the combustion cylinder. As soon as marine surveyors are confronted with engine malfunctions involving damage to pistons, rings, liners, valves and cylinderheads, they are asked to give their view on the cause of the malfunction. Especially when no severe damage to the parts is visible and only an extreme amount of deposits are present or abnormal wear is measured, their task is not a simple one. In these cases thorough investigations are necessary to assess the cause. In most of these cases, the combustion quality has to be investigated. It is always important to collect samples of the deposits, of the lubricating oil out of the engine sump or circulation tank and of the fuel out of the daily service tank. By analysing the samples one will often be able to find the cause of the malfunction.

The sequence of combustion problems throughout the years

During the last fifteen years, the nature of diesel engine combustion problems has changed several times. Before 1985, engines suffered from corrosion and carbon deposits. Between 1985 and 1992 liner lacquering and bore polishing were the main problems. Between 1992 and 1995, bore polishing and piston undercrown deposits.

Fuel sulphur

The quality of the combustion is dependent on the quality of the fuel. The fuel quality must meet the requirements of various specifications. Sulphur can lead to corrosion and wear of engine systems (Figure 2). Sulphur can have a significant effect on engine life. As shown in Figure 6 of the World Wide Fuel Chapter (Appendix D), as sulphur level increases, relative engine life decreases. Furthermore the efficiency of some exhaust after-treatment systems is reduced as fuel sulphur content increases, while others are rendered permanently ineffective through sulphur poisoning. As sulphur levels are reduced, fuel stability requires special attention.

Figure 2 - Fuel Sulphur Damage

The industry has developed a "Standard Test Method for High Temperature Stability of Distillate Fuels" (ASTM D 6468) for thermal oxidative stability. Inadequate thermal stability can result in fuel filter plugging. As fuel injection system pressures and temperatures increase, it may be more appropriate to measure the thermal oxidative stability of diesel fuel rather than only long-term storage stability. During the combustion process, sulphur in the fuel results in sulphuric acid. A large part of the acid disappears as gas, together with the other exhaust gases. A smaller part condensates at the surface of the cylinder liner. The acid is neutralised at the liner wall by the alcalic additives of the lubrication oil in order to prevent oxidation of the liner. However, insufficient cooling water and charge air temperatures increase the amount of condensated acid. It is important that the wall temperature of the cylinder liner is above the sulphuric acid dew point. Further one should select the correct oil with a Total Base Number which is 20 times the fuel sulphur content in order to counteract acid formation. During incomplete combustion, an abnormal amount of soot is produced. Most of it leaves the engine together with the other exhaust gases. A small part will be absorbed by the lubricating oil on the surface of the cylinder liner. Soot has the quality of absorbing sulphuric acid. Consequently, when an abnormal amount of soot is produced, more sulphuric acid will come into the lubricating oil and this will lead to a reduction of the Total Base Number.

Total Base Number (lubrication oil) - sulphur
The Total Base Number gives an indication of the quantity of the alcalic additives in the lubricating oil. The function of the additives is to neutralize the sulphuric acids, resulting from the fuel combustion process inside the cylinders of the diesel engine. This neutralising is necessary in order to prevent corrosion during the burning of sulphur. Also, wear of the cylinder liner and piston rings will be limited. The TBN is measured in equivalent potassium hydroxide. The combination of additives is based on the running circumstances of the engine as well as on the amount of sulphur in the fuel. The calcium carbonate of the alcalic additives is transformed by the sulphuric acid into the harmless calcium sulphate. This results in reduction of the TBN while the quantity of calcium remains on the same level. The oil additives determine the quality and performance of every different oil type. The composition of the different additives used by the oil companies in their oils not published. Abnormal reduction of the TBN can be caused by among other factors running on fuel containing too much sulphur.

Cylinder liner lacquering - sulphur
Lacquering is evidenced by the formation of a yellow to dark brown deposit layer on the cylinder liners. Not all engine makes or types show liner lacquering. High BMEP (Brake Mean Effective Pressure) engines are more affected than engines with moderate BMEP's. All applicable oils of the established oil companies suffer from this lacquering phenomenon. Lacquering is reported mainly where low sulphur gas oil is used. Specialised additives are as vital in fuels as they are in lubricants. There is a large aftermarket with a wide range of fuel and lubricating oil additives that are designed to enhance the performance of existing fuel and oil properties (e.g. anti-lacquering, cold flow, lubricity and cetane number) as well as adding new performance features to the fuel.

Engine Manufactures Association (EMA) Ultra low sulphur diesel fuel recommendations
The EMA has made several recommendations in order to run diesel engines using ULSD. With the introduction of ULSD the EMA recommends all diesel fuel meet the minimum requirements of ASTM D 975 as well as additional performance requirements as described in appendix F.

Appendix A: Geographical spread of the survey

Gas oil used by inland vessels

EN-590 Diesel

Appendix B: Lubricity results inland vessel gas oil Netherlands

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CENTRAAL BUREAU VOOR DE
RIJN- EN BINNENVAART
Postbus 23133
3001 KC Rotterdam

ANALYTICAL REPORT SR-1136722.01.A02

P.1/2

grade	GASOIL
sample 001	Monster 1
sample 002	Monster 2
sample 003	Monster 3
sample 004	Monster 4
sample 005	Monster 5
date received	09.03.2007
start analyses	10.03.2007

	001	002	003	004	005
Lubricity corrected wear scar diameter, µm (ISO 12156-1)	407	426	404	407	289
Sulphur, % wt (ASTM D 2622)	0.120	0.119	0.176	0.111	0.179

ANALYTICAL REPORT SR-1136722.01.A02

P. 2/2

sample 006	Monster 6
sample 007	Monster 7
sample 008	Monster 8
sample 009	Shell 05-03-07
sample 010	BP Gasolie Victoria
date received	09.03.2007
start analyses	11.03.2007

	006	007	008	009	010
Lubricity corrected wear scar diameter, µm (ISO 12156-1)	419	371	406	415	414
Sulphur, % wt (ASTM D 2622)	0.184	0.183	0.155	0.180	0.163

Samples will be retained for 3 months unless instructed otherwise.
End of analytical results

Appendix B continued: Lubricity results inland vessel gas oil Germany

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3001 KC Rotterdam

ANALYTICAL REPORT SR-1142366.01.A01 P.1/1

grade	GASOIL
sample 001	Sample 1
sample 002	Sample 2
date received	17.04.2007

	001	002
Lubricity corrected wear scar diameter, µm (ISO 12156-1)	485	412
Sulphur, % wt (ASTM D 2622)	0.158	0.135

Samples will be retained for 3 months unless instructed otherwise.
End of analytical results

Appendix C: Lubricity results (N)EN-590 Netherlands - Germany

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CENTRAAL BUREAU VOOR DE
RIJN- EN BINNENVAART
Postbus 23133
3001 KC Rotterdam

ANALYTICAL REPORT SR-1138382.01.A01 P.1/1

grade	GASOIL
sample 001	BP Groene Kruisweg Rotterdam
sample 002	Shell Aveling Hoogvliet
sample 003	Esso Tramdijk Spijkenisse
date received	23.03.2007
start analyses	27.03.2007

	001	002	003
Lubricity corrected wear scar diameter, µm (ISO 12156-1)	373	221	310
Sulphur, % wt (ASTM D 2622)	0.0005	0.0006	0.0007

SGS

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To whom it may concern

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Deutscher Akkreditierungs Rat
DAR
DAC-PL-0441-00-20

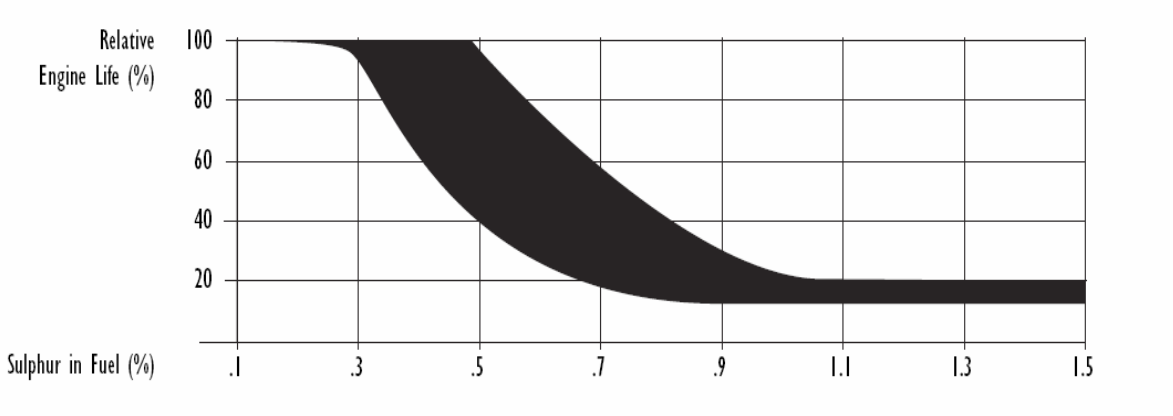
Final Report : SP07-01113 / Client Order No: 873922

Page 1 of 1

SGS Sample No:	SP07-01113.001
SGS SAP Order No:	873922
Designated Product:	Diesel
Packaging:	Metal can
Sample Volume:	5 l
Received:	19.04.2007
Client reference:	StNr. 27/143/81076
Sample Label:	Esso Station Rainer Samstag Mundenheimer Str. 74 67061 Ludwigshafen

Test / Analyte	Test Method / Norm	Result	Unit
Sulfur content	DIN EN ISO 20846	8.0	mg/kg
Lubricity	DIN ISO 12156-1		
HFRR WS 1.4		238	µm

Appendix D: World Wide Fuel Chapter figure 6 Effect of Sulphur on Engine Life



Appendix E: ASTM Fuel Specification

Property	ASTM Method	Limits	Units
Flash Point	D93	52 min.	°C
Water and Sediment	D2709	0.050 max	% vol.
KinematicViscosity,40C	D445	1.9 - 4.1	mm2/sec.
Ash	D482	0.01 max.	% mass
Sulfur (Grade No.2)	D129	0.50 max.	% mass
Sulfur (Grade No. 2-Low Sulfur)	D2622	0.05 max. will change to 0.0015	% mass
Copper Strip Corrosion	D130	No. 3 max.	
Cetane	D613	40 min.	°C
Pour Point	D97	-	°C
Cloud Point or LTFT/CFPP	D2500 D4539/D6371	Depends on location Depends on location	% mass
Density, 15°C	D1298	-	kg/m3
Ramsbottom Carbon Residue	D524	0.35 max.	mg KOH/gm
Cetane Index or Aromaticity	D976 D1319	40 min. 35 max.	 % vol.
Distillation Temperature, 90% Recovered	D86	282-338	°C
Lubricity, HFRR @ 60°C	D6079	520 max	microns

Appendix F: Additional requirements EMA

Engine Manufacturers Association Recommendations for Ultra Low Sulphur Diesel Fuel		
Specifications	ASTM Test	Requirements
Cetane	D613	40
	D4737-90a	42.5
Lubricity	D6078	3100 Grams
	D6079	450 Micrometers Max @ 60 C
Thermal Stability	D6484	70% Reflectance after 180 Minutes @ 150 C

Appendix G: An excerpt from the NEN-590 Fuel Specifications

Property	Unit	Limits		Test method
		Minimum	Maximum	
Cetane number		51	-	EN ISO 5165
Cetane index		46	-	EN ISO 4262
Density at 15 °C	kg/m3	820	845	EN ISO 3675 EN ISO 12185
Polycyclic aromatic hydrocarbons	% (m/m)	-	11	EN ISO 12916
Sulphur content	mg/kg	-	10	EN ISO 20846 EN ISO 20847 EN ISO 20884
Flashpoint	°C	Above 55	-	EN ISO 2719
Carbon residue	% (m/m)	-	0.3	EN ISO 10370
Ash content	% (m/m)	-	0.01	EN ISO 6245
Water content	kg/m	-	200	EN ISO 12937
Total contamination	kg/m	-	24	EN 12662
Copper strip corrosion	rating	Class 1		EN ISO 2160
Oxidiation stability	g/m3	-	25	EN ISO 12205
Lubricity, corrected wear scar diameter (wsd 1.4) at 60 °C	µm	-	460	EN ISO 12156-1
Viscosity at 40 °C	mm2/sec.	2	4,5	EN ISO 3104

Appendix H: References

Shell Nederland Verkoopmaatschappij B.V.
D. TOUW Expertise en ingenieursbureau B.V.
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