IVR report

on the impact on implementation of low sulphur fuel in seagoing per 1-1-2010 and inland navigation per 01-01-2011 from a practice viewpoint

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CONTENT

1. Summary

The European Union adopted directive 98/70/EG dealing with reduction of emissions, especially where inland shipping exhaust gas emissions are concerned. This directive together with EU Directive 1999/32/EC and 2005/33/EC amendments required reduction of gas oil sulphur level to a maximum of 10 ppm as per 1st of January 2010 for coastal waters, ports and inland navigation. EU Directive 2009/30/EC of 23rd April 2009 however resulted in postponement of implementation of low sulphur gas oil with a sulphur level of maximum of 10 ppm for inland navigation until 1st of January 2011.

Originally the European Committee in improving emission of inland navigation a few years ago intended to introduce one type of low sulphur fuel spec, being the EN590. However, this was let loose and the final directive only gives limits to the maximum sulphur content in gas oil for inland shipping being maximum 10 ppm or 0,001 % m/m.

EN590 itself is a high quality low sulphur fuel which, in the “modern” engines will perform well, will give a good clean burn, has a slightly lower density resulting in a slightly higher fuel consumption which is more or less compensated by it’s somewhat higher heating value and its lubricity is due to additives acceptable. It’s even the case that the so-called “modern” engines are required to use fuel with less than 50 ppm anyhow.

However, due to the fact that only the maximum fuel sulphur content is regulated by the EU directive, it cannot be excluded that different qualities of gas oil will be supplied throughout Europe, which, although most probably applying to the maximum allowed sulphur content, on different fuel specifications might be less up to standard than would be desirable.
EN590 will be more expensive than other gas oils which most probably will have a lesser quality and the risk of not having enough lubricity additives as are added to EN590.
Therefore it cannot be excluded that these less expensive gas oils will result in wear of the fuel system components, resulting in incorrect combustion with experienced resulting engine damages.

It is a fact that quite a number of vessels (estimated fore instance approx. 84% of the Dutch inland vessels) are equipped with “older” propulsion- and auxiliary engines which are less equipped for low sulphur fuel. These so-called “older” engines are more susceptible to wear of fuel system components with all resulting consequences. Also fuel system component seals of the “older” engines might suffer leakage when using low sulphur fuel.

For all engines finding a new balance between the low sulphur fuel end lube oil TBN[1] will be required.

All considering, it can be stated that implementing low sulphur fuel in the inland shipping is no problem provided that, in consultation with engine manufacturers and lube oil suppliers, possible required modifications at the engine and its fuel systems are carried out, lube-oil TBN is well adjusted to the low sulphur fuel and good, preferably EN590, spec fuel is bunkered.

For seagoing vessels which sail worldwide, EN590 will not be worldwide available and the requirement of using low sulphur fuel in certain areas will confront ship owners with quite some different problems than will occur in inland shipping.
Seagoing vessels are confronted with a wide range of world wide (low sulphur) fuel suppliers and fuel quality (or the lack thereof), will require more frequent change over from heavy fuel to low sulphur fuel and related procedures must be reviewed. Fuel systems as well as boilers and emission treatment plants in many cases will have to be modified in consultation with manufacturers and Class associations.
Also lube oil, pending on 4- or 2 stroke engines, needs to be adjusted or liner lubrication flow to be adjusted when changing over to low sulphur fuel. All in close consultation with engine manufacturers.

[1] Total base number (TBN) is a measure of a lubricant's reserve alkalinity. It is measured in milligrams of potassium hydroxide per gram (mg KOH/g). TBN determines how effective the control of acids formed will be during the combustion process. The higher the TBN, the more effective it is in suspending wear-causing contaminants and reducing the corrosive effects of acids over an extended period of time. Marine grade lubricants generally will run from 15-50mgKOH/g, but can be as high as 70 or 80mg KOH/g this high level is designed to allow a longer operating period between changes, under harsh operating conditions.
When the TBN is measured at 2mg KOH/g or less the lubricant is considered inadequate for engine protection, and is at risk for allowing corrosion to take place. Higher sulphur fuel will decrease the TBN faster due to the increased formation of sulphuric acid.

For inland- as well as seagoing vessels mixing of fuels (HFO and LSFO[2] as gas oil and bio-fuels) is to be avoided as much as possible.

Close monitoring of fuel systems, fuel treatment plants as well as frequent fuel and lube oil quality checks by analyses and creating awareness about the importance of good change-over procedures will be necessary to avoid unnecessary wear and damages to installations.

The EU only regulated the maximum allowed sulphur content and left all other also important fuel specification to secure good combustion and limited wear and limited damage risks to the propulsion installation unregulated.

In view of the fact that low sulphur fuel with good lubricity characteristics is expected to be somewhat more expensive, owners might choose for less expensive low sulphur fuel qualities, which will undoubtedly result in wear of fuel pump and injection components, bad combustion and resulting engine wear and damages.

[2] *HFO (Heavy Fuel Oil)* is fuel which remains of the crude oil after gasoline and the distillate fuel oils are extracted through distillation.
LSFO (Low Sulphur Fuel Oil) is a special type of bunker fuel that has a sulfur content of 1.0% maximum.

2. Introduction

The European Union adopted directive 98/70/EG dealing with reduction of emissions, especially where inland shipping exhaust gas emissions are concerned. This directive requires, together with EU directive 1999/32/EC and 2005/33/EC amendments, reduction of gas oil sulphur level to a maximum of 10 ppm (0,01% m/m[3]) as per 1st of January 2010. EU Directive 2009/30/EC of 23rd April 2009 however resulted in postponement of implementation of low sulphur gas oil with a sulphur level of maximum of 10 ppm for inland navigation until 1st of January 2011.

The Dutch Ministry of Environment and Spatial Planning (VROM) has asked TNO to review the potential consequences of the introduction of EN590 sulphur free gas oil for the inland navigation sector.
TNO has in line with this request carried out a study which was reported in TNO's report "Review of potential issues for inland ship engines when reducing gas oil sulphur level to maximum 10 ppm" report nr.MON-RPT-033-DTS-2007-01813 dated 29th June 2007.

On request of the German Ministry of Transport, Building and Urban Developments a study was carried out by Jowa Germany GmbH regarding the tolerance of low sulphur fuel (sulphur content less than 10 ppm) with bio parts with older operational engines in the inland shipping. Jowa has reported its findings in report nr. 30.00331/2007 dated august 2007.

The overall conclusion of the TNO study is that EN590 sulphur free gas oil is compatible with all types of engines used for inland navigation application. For engines sensitive to cylinder liner lacquering, this will tend to decline. However the balance in engine operating conditions and lubricant type may need adjustment. The good compatibility of sulphur free gas oil is also supported by experience with marine fleets around the world which have already switched to sulphur free or to low sulphur gas oil.

The overall conclusion of the Jowa study is that low sulphur or sulphur free gas oil as well as a mixture of biogenic fuel elements to a maximum of 5% with the present available knowledge is possible in older engines and boiler installations in the German inland shipping. Hereby good fuel quality and storage needs to be observed and maintained.

Abstracts from the TNO and Jowa report are used in this report to explain technical and chemical issues of the refinery process and gas oil components.

The IVR feels the necessity to comment on the conclusions drawn in for mentioned reports from a practical viewpoint, in order to highlight the technical and risk consequences in practice when implementing low sulphur or sulphur free gas oil.

Seagoing will be confronted with low sulphur fuel requirements and new regulations as per 01-01-2010.

Low sulphur requirements in SECA[4] will on seagoing vessels have effect on fuel change-over procedures, installations and technical measures to be undertaken to avoid increase of damage risks. All Class associations have a wide scope of information available on how to deal with these new developments and requirements and together with engine-, boilers- and fuel treatment equipment manufacturers can assist ship owners to modify installations and procedures in order to apply correctly to the regulations and avoid components wear and damage risk increase.

In view of the fact that low sulphur free gas oil is required to be bunkered in EU ports for seagoing vessels, it cannot be excluded that also quite a number of inland vessels will, maybe unknowingly, also be bunkered with low sulphur fuel as per 1st of January 2010, whilst legally only being required as per 1-1-2011.
The impact of low sulphur fuel implementation in inland shipping as per 01-01-2011 is less severe, but also its practical consequence are less known and documented.
Therefore this report will mainly focus on the effects for inland vessels propulsion installations and only touch upon the consequences for seagoing vessels.

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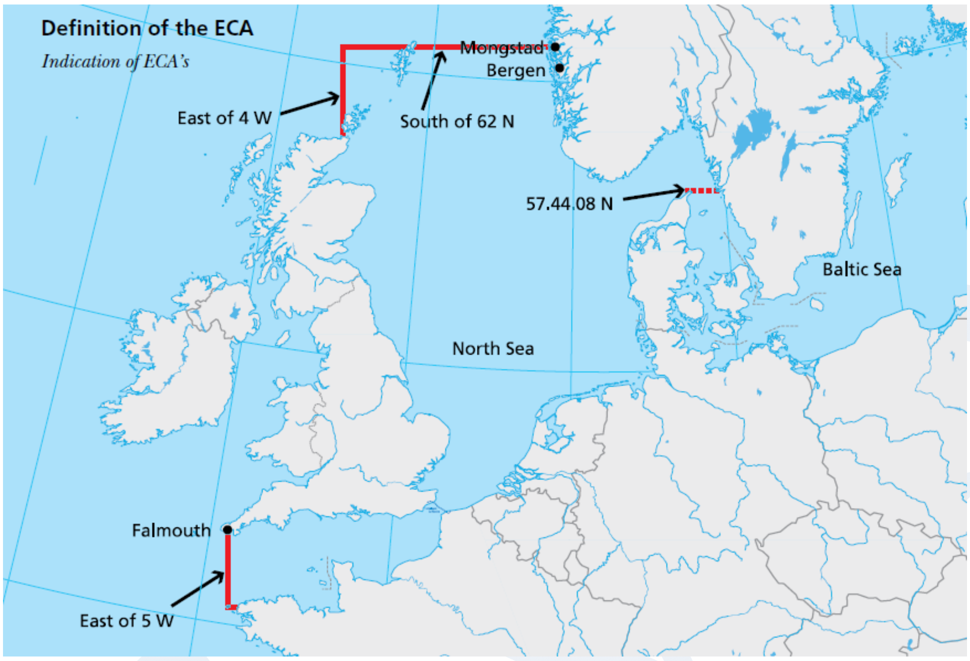
3 m/m : mass to mass percent.
4 SECA = Sulphur Emission Control Areas

3. General

3.1 Seagoing vessels

Seagoing vessels will, as per 01-01-2010 due to various international and regional legislation by the European Union directive 2005/33/EC, the California Code of Regulations title 13/17 and MARPOL (the International Convention for the Prevention of Pollution from Ships 1973) Annex VI, be required to apply to low sulphur fuel requirements in the Sulphur Emission Control Areas (SECA). The indication of this area in the European region is show on below map.



Below ship type and fuel requirements and areas are shown.

Ship type	Area	%	When	Note
All	Baltic SECA	1.5	11.8.2006	1
All	North Sea + English Channel SECA	1.5	11.8.2007	1
All	All EU ports	0.1	1.1.2010	2,3,4
Passenger ships	All EU	1.5	11.8.2006	4,5
Inland waterway vessels	All EU inland waterways	0.1	1.1.2010	

1. MARPOL Annex VI defined SO_x Emission Controlled Areas (SECA).
2. Except for ships due to be at berth less than 2 hours.
3. Derogation for 16 Greek ships operating within Greece until 1.1.2012.
4. Not applicable in the outermost regions of the Community (French overseas departments, Azores, Madeira, Canary Islands).
5. Operators of cruise ships making regular cruises are advised to check with relevant authorities whether their operation is affected by the definition in the Directive: "Passenger vessels on regular services to or from any Community port (= a series of passenger ship crossings operated so as to serve traffic between the same two or more ports, or a series of voyages from and to the same port without intermediate calls, either (i) according to a published timetable, or (ii) with crossings so regular or frequent that they constitute a recognisable schedule)."

For seagoing vessels different fuels are presently available, whereby according to ISO 8217, the upper sulphur content limit for these fuel grades is as follows:

- Marine Gas Oil (MGO): 1.50% m/m
- Marine Diesel Oil (MDO): 2.00% m/m
- Heavy Fuel Oil (HFO): 3.50-4.50% m/m depending on the categories and the viscosity therein

The new directives require the following with respect to low sulphur fuels;

- low sulphur of any grade of fuel used in EU community ports, at berth, means sulphur less than 0.1% after 01-01-2010
- low sulphur MDO under Californian regulations means sulphur less than 0.5% (0.1% after 01-01-2012)
- low sulphur MGO under Californian regulations means sulphur less than 1.5% (0.1% after 01-01-2012)
- low sulphur of any grade in IMO-regulated Emission Control Areas (ECA) means sulphur less than 1.50% prior to 01-07-2010
- low sulphur of any grade in IMO-regulated Emission Control Areas (ECA) means sulphur less than 1.00% after 01 -07-2010
- low sulphur of any grade in IMO-regulated Emission Control Areas (ECA) means sulphur less than 0.10% after 01-01-2015

Seagoing vessels are equipped with 4- or 2 stroke engines for propulsion purposes, power supply and auxiliary power supply with a wide range of power, rpm's ranging from 800 kW at 1.000 rpm up to 80.000 kW at 92 rpm.

The impact for seagoing vessel with respect to changing over to low sulphur fuel in the SECA areas is much more extensive than for inland vessels which per 01-01-2010 have to change to fuel with a max. sulphur level of 0,2 to 0,1 % m/m, but are not confronted in having to change over frequently from different types of fuel due to the area they operate in.

Ships using separate fuel oils are required when entering or leaving an Emission Control Area to carry a written procedure showing how the fuel oil change-over is to be done, allowing sufficient time for the fuel oil service system to be fully flushed of all fuel oils exceeding the applicable sulphur content prior to entry into an Emission
Control Area. Change over procedures need to be documented in a logbook. In the log-book volume of low sulphur fuel oils in each tank, date and time, ship's positions at the start and completion of change-over must be recorded.
Change-over between heavy fuel oil grades is standard practice and so is change-over from heavy fuel oil to marine diesel oil in connection with e.g. dry-dockings.
Change-over from heavy fuel oil to marine gas oil is however completely different and clearly not common standard. If gas oil is mixed in while the fuel temperature is still very high, there is a high probability of gassing in the fuel oil service system with subsequent loss of power.

The experience in terms of low sulphur residual (or heavy) fuel oil blending is varying. Indications are seen that the blending of low sulphur fuel oils may lead to additional quality problems such as instability, incompatibility, ignition and combustion difficulties and an increase of Aluminium and Silicon levels due to use of different low sulphur blend components. Regrettably one has also seen cases where chemical waste has been introduced in such fuel. In light of the required demand for low sulphur fuel oils, there have also been concerns over the potential increase of sulphur content in high sulphur fuel oils.

Ship operators should assure that the LSFO (Low Sulphur Fuel Oil) oil is compatible with the HSFO (High Sulphur Fuel Oil) by sending a representative sample of each fuel oil quality to a fuel oil testing company. Blending high density fuel oil with low density fuel gives the highest risk of incompatibility, while blending two low density fuel oils represents the lowest risk. The blending ratio should in any case be as small as possible.

The consequence for seagoing vessels has not only an impact on change-over procedures but also on use and choice of lube oil TBN level and the technical consequences thereof.

High total base number (TBN) lube oil in combination with low-sulphur fuel increases the risk of scuffing on the cylinder liner. The deposits are more solid when less oil TBN additives are neutralised by sulphuric acid. Therefore careful monitoring of the cylinder liner condition when operating on low sulphur fuel oil, and if necessary change to low TBN cylinder oil or reduce the feed rate in accordance with the engine makers recommendations will be required.

Apart from consequences for the propulsion installation also boilers and exhaust gas cleaning systems on board seagoing vessels will be affected by the use of low sulphur fuel and will require technical adaptations as well as review of cleaning and maintenance procedures in order to avoid increase of damage risks.

Boilers are the component most at risk when switching over from HFO to use 0.1 % sulphur Medium Diesel Oil (MDO). Boilers on board can be divided in 3 categories: “small”; “large” boilers and boilers used for propulsion.

Small boilers are installed on board all types of vessels and can run purely on MDO. However an assessment for each boiler is advisable and most probably modification will be required.

Large boilers are commonly installed on tankers to produce steam for cargo operations. As for all other boilers, individual assessments will be also needed before modifications.

Boilers used for main propulsion, shipboard electricity generation and cargo operations. This type of boiler is commonly fitted on board LNG carriers. These also will require extensive modifications in order to be able to run on low sulphur fuel without increasing wear and damage risks.

3.2 Inland vessels

Introduction of EN590 was originally intended to be a 100% replacement for the current VOS/DIN specification with maximum sulphur content of 1000 ppm. However the EU directive has been changed in this respect that gas oil sulphur content in general should not exceed 10 ppm and further specs of the EN590 are not mandatory. It cannot be excluded that in the future maximum sulphur content will even be further lowered to 0,5 ppm. Also it is likely that in the near future limits to exhaust gas emissions will become mandatory.

EN590 sulphur free gas oil has the following advantages:

a) it leads to a reduction of SO_2 and particulate emissions for all ships,
b) it is necessary for future engine emission control technologies such as EGR (Exhaust Gas Recirculation) and exhaust after treatment systems (it is also specified by the engine manufacturers for modern, new engines),
c) it would allow for cost effective retrofit after treatment systems such as DPF (Diesel Particulate Filters) and selective catalytic reduction of NO_x.

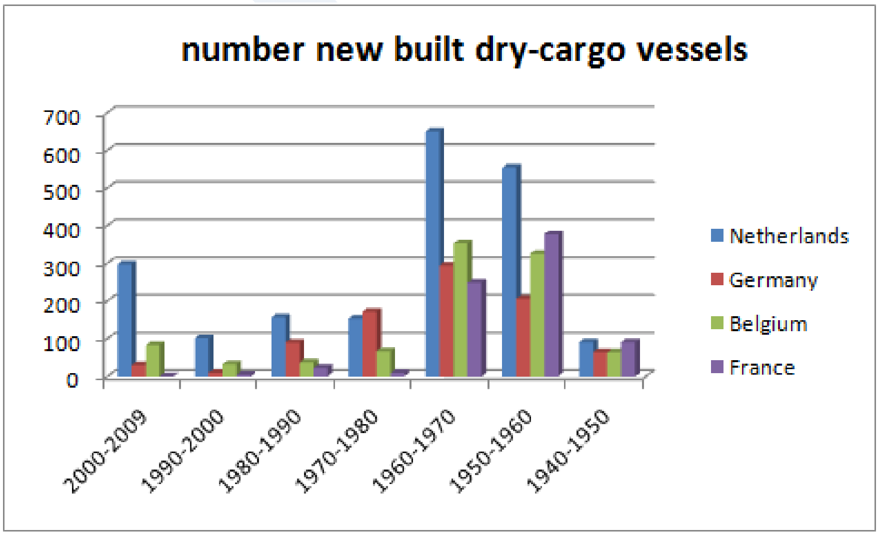
In Europe there is no general quality specification for marine gas oil. In most countries the marine gas oil quality aligns with off-road diesel or heating gas oil specifications.
In this report properties like lubricity, density, viscosity and lacquering tendency are discussed and the refining processing effects are qualified.

Inland vessels are mainly equipped with high or medium speed 4-stroke engines for propulsion purposes, power supply and auxiliary power supply ranging from 500 kW at 2.100 rpm up to 2.500 kW at 1.000 rpm.

The new modern engines are developed with new fuels like low sulphur, bio fuels etc. in mind.

Looking however to the year of construction of the present inland (dry-cargo) vessels, there are not many equipped with a new modern engine. In general it can be concluded that vessels older than 30 years in the recent 5-10 years have been equipped with new engine, due to severe damage to the propulsion installation, due to normal renewal and supported by national subsidy programs to improve inland navigation emission levels.

One might consider engines no older than 5 to 10 years as “modern” engines, equipped with common rail fuel systems and designed with alternative fuels in mind.



Source IVR database

From for mentioned graph it can be concluded that 68% to 84% of the present dry-cargo vessels have been built in the period between 1960 and 1980.

It is unknown of how many vessels the original engine has been renewed and after which time from date of new building of the vessel.

From the figures of the Dutch inland dry-cargo fleet more information is available with respect to the age of propulsion engine. It can be concluded that 40% of the engines are older than 30 years and about 38% is older than 20 years.
Only 18,2 % of the Dutch dry-cargo vessels are equipped with propulsion engines dating from 2000 or later today and which might be considered as so-called “modern” engines.

From the TNO and Jowa reports can be concluded that the “modern” engines can run on EN590 low sulphur fuel without almost any problems where fuel system is concerned.

This report will mainly focus on the consequence of low sulphur fuel for the majority of engines not being the “modern” engines manufactured and installed between 1970 and 2000, representing for instance 84.6% of the Dutch dry-cargo fleet.

4. Gas oil specifications

The undersigned in the 80ties had, as board member of the VOS (Vignet Olie Scheepvaart), close involvement in the setting up of the Dutch VOS gas oil specification.

The latest (2008) VOS specification is almost fully aligned with the German DIN specification. VOS includes some additional requirements for acid number, cetane index (min. 45) and a slightly higher flashpoint to be fulfilled in case of deliveries to seagoing vessels. The VOS specification is however only maintained by the Dutch wholesale association and has no international status.

When comparing EN590 and VOS specifications the emerging differences are:

- Cetane index: Cetane Index being the ignition quality of a fuel for which a minimum cetane index of respectively 46 and 45 is required;
- Density: Density of VOS has a max. of 860 whilst EN590 density is to be between 820 and 845 at 15°C;
- Viscosity: The viscosity criteria of VOS is specified at 20°C whilst EN590 measures it's spec at 40°C mm^2/s which makes a correct viscosity comparison more difficult and will be confusing towards the market.
- Hydrocarbons: VOS fuel doesn't give specs for polycyclic aromatic hydrocarbons whilst this with EN590 is limited to max. 11 % m/m. Also oxidation stability and flash point specifications differ somewhat between the EN590 and VOS;
- Cold flow properties: For EN590 each member state includes an appendix setting the cold flow requirements for their specific weather conditions. In the Rhine area in winter normally operability down to -20 °C is guaranteed by selecting lighter refinery components and including cold flow additives. For marine application the more expensive EN590 winter quality has no added value as the gas oil is normally stored below the waterline. The VOS requirements are more relaxed.
- Total Acid Number: VOS specifies the Total Acid Number whilst EN590 does give any specification, whereas VOS doesn't specify oxidation stability and EN590 does;
- Bio component: As mentioned before the EN590 allows the inclusion of FAME (fatty acid methyl ester, normally based on a vegetable oil). In the VOS specification these components are not addressed. In principle, for marine application, bio components have no added value, but the volumetric energy content will reduce and the risk of contamination and deposit formation may increase.
- Lubricity: Both VOS and EN590 give maximum 460 µm scar diameter as indication for required fuel lubricity.

It has to be established that the VOS, German DIN 51603-1 and EN590 differ, which will reduce the clarity of fuel specifications for the customer.

Specifications of VOS and EN590 and related measure methods are shown respectively in table 1 and table 2.

	VOS specification	Method
Apperence at 20 °C	Clear and free of visual water and contaminations	Visual
Color	red	Visual
Density at 15° C	max. 860	ISO 12185
Viscosity at 20 °C mm^2/s	max. 6.0	ISO 3104
Cetan index	min. 45	ISO 4264
Sulphur content % m/m (ppm)	max. 0,001 * (10 ppm)	ISO 20847 / ISO 20884
Flash point	min. 60 "	ISO 2719
Cloud point max. °C	max. +3	ISO 3015
CFPP as function of cloud point, °C		EN 116
at + 3 °C	-12	
at + 2 °C	-11	
at + 1 °C	-10	
Micro Carbon residue		
after 10% destillation, % m/m	max. 0,30	ISO 10370
Ash, % m/m	max. 0,01	ISO 6245
Total Acid Number, mg KOH/g	max. 0,5	EN 12634
Destillation		ISO3405
Evaporated at 250 °C, % vol	max. 65	
Evaporated at 350 °C, % vol	max. 85	
Water	max. 200	ISO 12937
Total Contamination, mg/kg	max. 24	ISO12662

* when sulphur content is less than 0,05 % m/m (50 ppm) attention to be given to lubricity - max. 460 µm according to ISO 12156-1
" if fuel is only used in inland shipping: min. 55°C

Table 1

	EN 590	Method
Apperence at 20 °C	Clear and free of visual water and contaminations	Visual
Color	red	Visual
Density at 15° C	min. 820 - max. 845	ISO 12185
Viscosity at 40 °C mm^2/s	min. 2 max. 4,5	ISO 3104
Cetan index	min. 46	ISO 4264
Cetan number	min. 51	ISO 5165
Sulphur content % m/m (ppm)	max. 0,001 % m/m (max. 10)	ISO 20847 / ISO 20884
Polycyclic aromatic hydrocarbons % m/m	max. 11	ISO 12916
Flash point	> 55	ISO 2719
Cloud point		ASTM D 2500
summer quality	max. 4	
intermediate	max. 0	
winter quality	max.-7	
CFPP as function of cloud point, °C		EN 116
summer quality	max. -5	
intermediate	max. -11	
winter quality	max.-20	
Micro Carbon residue		
after 10% destillation, % m/m	max. 0,30	ISO 10370
Ash, % m/m	max. 0,01	ISO 6245
Oxidation stability g/m^3	max. 25	ISO 12205
Destillation		ISO3405
Evaporated at 250 °C, % vol	max. < 65	
Evaporated at 350 °C, % vol	max. 85	
Evaporated at 360 °C, % vol	max. 95	
Anti friction property at 60 °C	max. 460	ISO 12156-1
Water mg/kg	max. 200	ISO 12937
Total Contamination, mg/kg	max. 24	ISO12662

Table 2

5. Sulphur as gas oil component

General

Sulphur is a natural component in crude oil in a wide variety of compounds and can vary excessively per crude oil production location. If the sulphur is not removed during the refinery process it will be converted to sulphur oxides in the engine combustion process.

Sulphur oxides may react with water from the air passing through the cylinder and form corrosive substances like sulphuric acid. Especially when the engine is cold the acid may condensate on the surface of the cylinder liner. The acid is neutralised by the alkali components in the lubricant (Total Base Number (TBN)) in order to prevent corrosion of the liner.
In the past unbalance between the fuel sulphur level and lube oil TBN has resulted in lacquering of liners, with consequential high lube oil consumption and carbon build up on pistons with increased damage risks.

Refinery process

During the hydrodesulphurisation (HDS) process the sulphur compounds are removed by converting them into hydrogen sulphide by reaction with hydrogen in the presence of a catalyst. This is a relatively new implemented process in the refinery industry.
The lower the level of sulphur in the product required, the higher the required pressure in the reactor needs to be. This is called the severity of the process.

Apart from the effect on sulphur level also other compounds are unwanted converted or removed, especially if process severity goes up. It will affect the amount of unsaturated hydrocarbons[5].

Lubricity

Trace compounds that gave conventional diesel fuel its lubricity are being removed by the HDS process. Reduced lubricity can result in excessive wear and premature failures of fuel injection equipment. The experts in the EN590 drafting committee agreed that a gas oil producing a wear scar diameter of less than 460 µm at 60°C under the condition of test, has a lubricity which is satisfactory for use with old and new fuel pumps. Refineries for this reason add a lubricity additive in case the EN590 requirement is not fulfilled.

Cetane quality

The cetane quality is expressed in the cetane number [6]of a gas oil and cetane index[7]. The higher this number, the shorter the ignition delays. Especially during starting conditions and the engine warming up period it has a positive impact on the combustion quality and the noise produced. In some emission tests also an emission benefit is recorded with engines running under full operation condition.

Gas oil stability

The HDS process will substantially reduce the unsaturated hydrocarbons. Especially these components tend to reduce the oxidation and thermal stability of the gas oil. Poor stability may result in the formation of gum and sludge during storage as well as deposit formation on injection nozzles and gumming of valves. Especially high speed direct injection engines are vulnerable. By reducing the unsaturated components with the HDS process, low sulphur gas oils have shown a positive contribution to the filter service live and the engine cleanliness.

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[5] When less than the full complement of hydrogen atoms is present in a hydrocarbon chain or ring, the hydrocarbon is said to be unsaturated. Unsaturated hydrocarbons are characterized by having two adjacent carbon atoms linked by two or three bonds instead of only one. These links are known as double bonds or triple bonds. They are not stronger than single bonds. On the contrary, they are surprisingly vulnerable, resulting in unsaturated compounds being more chemically reactive than saturates. Straight- or branch-chain hydrocarbons with one double bond are called mono-olefins or alkenes. Hydrocarbons with a double bond ring are called cyclo-olefins or cycloalkenes; those two double bonds in the structure are called diolefins or dienes.

[6] Cetane number is actually a measure of a fuel's ignition delay; the time period between the start of injection and start of combustion (ignition) of the fuel. In a particular diesel engine, higher cetane fuels will have shorter ignition delay periods than lower cetane fuels. Cetane numbers are only used for the relatively light distillate diesel oils. For heavy (residual) fuel oil two other scales are used CCAI and CII

[7] The cetane index is calculated from amongst others the distillation curve and density and is most of the time about 3 to 5 higher than the cetane number.

Viscosity
Gas oil viscosity may be slightly influenced by the HDS process. This may have an effect of increased bypass within the hydraulic mechanisms and result in slightly less fuel delivery.
For seagoing vessels low sulphur HFO and HFO typically have similar properties from the fuel injection point of view. However, some vessels may change over from HFO to LFO before arrival in SECAs. On these ships the effect on a HFO engine when operated on LFO needs to be considered.
For 4-stroke engines low fuel viscosity is generally speaking not a severe problem, but in severe cases with too low viscosity damage to the fuel injection equipment may occur, and the running parameters of the engine are affected. In exceptional cases there may be a risk of loss of capability to produce full power, black-out and starting problems.

Density
Density is a measure for the energy content; the higher the density the more combustible molecules per litre and the other way around. Density is affected by treating a gas oil with the HDS process. In the HDS desulphurisation process, heavy hydrocarbons like aromatics are converted in smaller molecules while the overall hydrocarbon hydrogen content is increased due to the increased saturating rate as well.

When looking at market surveys the average density of EN590 sulphur free diesel is in the range of 820 - 845 kg/m^3. In winter normally at the lower end and in summer slightly higher. The average DIN 51603-1 heating oil density is found in the range of 840 – 850 and according to the VOS specification its density is max. 860 kg/m^3 at 15 ^{o}C

This means that the move from DIN heating oil quality to EN590 will result in a measurable change in average density in the order of 10 to 30 kg/m^3. This will result in an overall a fuel consumption increase of approximately 0,5 to 1,5 %.

Acidity
The change in the fuel's acidity is not a problem for most boilers and is not a big problem as such for diesel engines.
For most diesel engines, the cylinder lubrication is based on the principle that the lubrication oil supplied to the cylinder contains sufficient alkaline additives to neutralise the corrosive effect of the acidic sulphur products formed during combustion. When the amount of sulphur in the fuel is reduced, the amount of neutralising additives should be reduced accordingly. The alkalic (or base) additives can be reduced by either selecting a different lubricant with a lower Total Base Number [8](TBN) or reducing the amount of lubricant supplied or a combination of both (for example with two-stroke engine). However the amount of oil supplied must remain sufficiently large to maintain a lubricating film on the cylinder liner.

Bio components
The marine gas oil quality according to DIN 51603-1 does not contain any bio component as the DIN standard does not allow for it. It is most likely that when the marine gas oil would follow the EN590 specification, bio components will be found.
In Germany the DIN EN590 will be replaced by DIN 51628 as per 31st of January 2010 relating to the bio oil component increased from 5 % V/V to 7 % V/V.
What may be the consequences?
In principle it helps the environment by reducing CO_2 emission. On the other hand its quality impact may be negative.
The negative aspects are;
- Separation of invaded water will be more difficult. This means that water may stay for longer time in emulsion making the fuel prone to microbial attack resulting in fuel system fouling. With good housekeeping these aspect may be manageable. This means; more frequent checks for tank water bottoms, filter fouling, prevention of any ingress of water and use of biocides in case of microbial contamination;
- Fuel consumption may tend to go up as the energy content is about 10 % lower compared to conventional gas oil (38 MJ/kg for bio fuel rather than 43 MJ/kg). Theoretically a 5 % V/V blend of FAME in marine gas oil will result in a 0,5 % consumption increase. Together with the average lower density of EN590 quality the overall effect may be measurable;

- Stability e.g. under storage and combustion may be an issue. Long term storage (more than a year), which may be practice in leisure marine, is not recommended.
- Experience related to marine engine cleanliness when using such components is limited. Diesel engine manufacturers have released all their engines for EN590 allowing for 5% (V/V) FAME[9] and it is assumed that older engines will not suffer when using up to 5%. In inland navigation however especially the house keeping aspects become more demanding. The effect of the increase of required bio fuel in DIN gas oil up to 7 % V/V as per 31 January 2010 in Germany, is not dealt with in this report and this aspect will be further commented upon in the near future.

9 Bio-diesel consists of fatty acid methyl esters (FAME)

6. Conclusions

The overall conclusion of this report is that changing from the former VOS/DIN gas oil specification (sulphur content maximum 2000 ppm) to EN590 or VOS sulphur free gas oil for inland navigation will not cause significant problems and only relatively simple adjustments to the fuel system of the “older” engines, although being significant in number, will be required. When changing over to EN590 or VOS sulphur free gas oil some typical engine wear issues will improve.
However, in view of the fact that the EU only regulated the maximum allowed sulphur content and left all other fuel specifications, also important to secure good combustion, unregulated. This can result in wear and damage risks to the propulsion installation.

Although implementation of low sulphur fuel legally is required per 1-1-2011, inland navigation might already, due to the fact that low sulphur free gas oil is required to be bunkered in EU ports for seagoing vessels per 1st of January 2010, it cannot be excluded that also quite a number of inland vessels will, maybe unknowingly, be bunkered with low sulphur fuel as per 1st of January 2010.

Bearing in mind that EN590 or VOS sulphur free gas oil will be more expensive, fuel consumption will increase slightly and EN590 or VOS sulphur free gas oil is presently limited available throughout the EU, the risk of ship owners choosing for general low sulphur gas oil with less specification and suppliers having the freedom of supplying gas oil with lesser specs, is present and will result in excessive wear to fuel system and engine components and eventually result in engine damages.
The lack of awareness within the inland navigation community with respect to the consequences of using low sulphur fuel not to EN590 or VOS sulphur free gas oil specification and lack of general awareness of owners of the so called “older” vessels, will increase for mentioned risks.

More in detail, the conclusions are as follows:

- EN590 sulphur free gas oil compared to VOS gas oil will have a higher cetane number and improved stability. Both low sulphur fuels will result in a better combustion and a clear burn with a positive effect on filter service live and engine cleanliness.
- Due to the HDS process for reducing the sulphur level from the basic crude oil in the refinery process, the lubricity is reduced. This reduction in lubricity properties is compensated by adding lubricity additives during the refinery process. It has to be pointed out that the VOS low sulphur gas oil specification doesn’t specifically indicate a maximum for an anti friction property at 60^{o}C, whereas the EN590 specifications do.
- Elastomeric[10] compatibility of low sulphur gas oil is slightly different. Basically sulphur free gas oil has a lower impact on the elastomers than the former 2000 ppm VOS/DIN gas oil. This might result in some seals in some engines which have always been running with 2000 ppm VOS/DIN gas oil and might pose a problem when switching to sulphur free gas oil.
- The typical engine wear issues of cylinder liner lacquering and bore polishing are expected to improve with the use of low sulphur gas oil due to the more complete combustion. The sensitive balance between operation conditions and lubrication oil in preventing this phenomena, as experienced in several engines, may need a new adjustment by testing other engine oil or cylinder oil formulations.
- The switch to low sulphur gas oil will have an impact on the average fuel density. As a consequence fuel consumption will increase by some 0,5 % and maximum power output will be reduced by some 0,5 %.

  On 4-stroke engines reduced density results in reduced energy content per stroke of fuel pump, reduced output at any fuel rack position. Depending on the 4-stroke engine type, the actual difference in output between LFO and HFO can typically be approx. 6…15 %, considering also the leakage due to low viscosity. This tendency may be further aggravated in older engines due to wear in the injection pumps.

  On 2-stroke engines in general, pump index limitations are not an issue regarding application of different fuel qualities. But when running on distillate fuel a slightly higher pump index can be expected

[10] Elastomer is a formation of a thermoplastic or thermoset that can stretch and then return to its original shape without permanent deformation.

compared to HFO operation. This adaptation is made automatically by the speed governor. The injection pumps as well as torque limiter and charge air limiter however have sufficient margin for safe engine operation. However, during exceptional conditions, such as a combination of an old engine with worn injection pumps, inappropriate adjustments, extreme weather and distillate fuel, these limiting devices may limit the available power. In case of doubt it is prudent to check the engine in case operation on distillate fuel in rough sea areas is foreseen (especially in case of small container ships).

On smaller 4-stroke engines most frequently used in the inland navigation, the "modern" engines with common rail systems low density will have only limited effect on the engines output. This will however in the older types be more of an issue.

- The blending of up to 5 % V/V Bio fuel, common practice in automotive diesel, will increase fuel consumption by another 0,5 % and require additional maintenance discipline to prevent fuel system fouling and deposit formation. As stated IVR in the near future will further comment on the increase to 7 % V/V of FAME in Germany as per 31-1-2010.
- Bio fuel blend might also cause problems for on board heating systems. Problems such as with seals, hoses and deposit formation. This can lead to a safety problem.
- Low sulphur gas oil will, due to their low flashpoint, on seagoing vessels have a negative impact on boiler burner flame pipes. These require to be replaced by ceramic pipes to avoid "metal dusting". Metal dusting is a severe form of corrosive degradation of metals and alloys at high temperatures (300-850^{o}C) in carbon-supersaturated gaseous environments. Fe, Ni and Co, as well as alloys based on these metals are all susceptible. The corrosion manifests itself as a break-up of bulk metal to metal powder-hence the term, metal dusting. Also, when low flashpoint fuels are being atomised with the help of steam, there is a chance that the fuel will evaporate before entering the boiler because of the steam temperature. Condensation of the atomizing steam may also be experienced when the steam get in contact with cold MGO. This may lead to poor combustion, an irregular burner flame or even flame extinction.

In general, low sulphur fuel will result in a cleaner combustion and emission, a cleaner engine, a somewhat higher fuel consumption and risk of fuel system components wear of older engines if no EN590 fuel with lubricity additives is used, possible risk of clogging in fuel system when mixing with bio fuel and risk of fuel system seals leakage. None of these should result in severe problems when care and attention is paid to the implementation of low sulphur fuel, its quality, correct modification of fuel systems of "older" engines, correct adjustment of lube oil specification and adjustment of change over procedures.

As stated before, the major worry however is that the EU directive only regulates the reduction of sulphur content and no other fuel specifications are addressed. In view of the fact that low sulphur fuel with good lubricity characteristics is expected to be somewhat more expensive (due to a more expensive refinery process and adding of lubricity improving additives), owners might choose for less expensive low sulphur fuel qualities, which will undoubtedly result in wear of fuel pump and injection components, bad combustion and resulting engine wear and damages.

7. Recommendations

In view of the findings and research results as stated in for mentioned TNO and Jowa reports as well as information obtained from research and publications on this subject by CBRB, DNV, MAN and Wärtsilä (reference is made to enclosed list of consulted documentation), combined with practice experience and the fact that for example 84% of the Dutch inland fleet consists of “older” type engines of which the fuel systems are more perceptible for reduced lubrication, IVR releases the following recommendations to the parties concerned:

1. Ship owners should contact engine manufacturers in order to establish if and if so which adaptations to the engine and it’s fuel systems are required when switching over to low sulphur fuel. These possible modifications will differ from make and type of engine, so engine manufacturers or dealers need to be consulted.
2. This consultation should be done soonest and not at normal overhaul period, because next normal overhaul might be scheduled too far away to avoid damage risks if the engine requires adaptations.
3. Fuel line seals need to be checked frequently with respect to possible leakage due to being affected by low sulphur fuel usage;
4. Usage of low sulphur fuel of EN590 specs in view of high spec quality is advisable for inland vessels
5. Lube oil TBN needs to be balanced with low sulphur fuel usage in consultation with the engine manufacturer and lube oil supplier;
6. Frequent lube oil analyses to monitor the effects on low sulphur fuel usage on the engine’s components is advisable;
7. Recording wear and soot deposit at normal overhaul for future references is advisable;
8. Adjustment of exhaust gas /emission treatment plants in consultation with manufacturers where required, is advisable;
9. For seagoing vessels switch over procedures need to be addressed and fuel systems adjusted in consultation with engine manufacturer and Class requirements;
10. Adjusting of burner flame pipes and boiler adjustments in consultation with boilers manufacturers is advisable;
11. Mixing of different fuels/fuel qualities needs to be avoided and special attention should be paid to fuel quality by means of regular sampling and documentation thereof;
12. Creating on board crew awareness on low sulphur fuel risk impact on fuel system components and fuel treatment plants (change-over procedures / mixing / fuel and lube oil quality check especially for seagoing vessels engine) is required.

It would be recommendable to develop one European standard for low sulphur fuel.

8. Consulted documents and reports

- Directive 2005/33/EC and 2007/0019/EC of the European Parliament and of the Council of 6 July 2005 and 31 January 2007amending Directive 1999/32/EC regards the sulphur content of marine fuels;
- TNO's report nr.MON-RPT-033-DTS-2007-01813 dated 29th June 2007 "Review of potential issues for inland ship engines when reducing gas oil sulphur level to maximum 10 ppm";
- Jowa Germany GmbH report nr. 30.00331/2007 dated august 2007– "Tolerance of low sulphur fuel (sulphur content less than 10 ppm) with bio parts with older operational engines in the inland shipping";
- Wärtsilä Low Sulphur Guidelines dated 9th January, 2006;
- Wärtsilä's report "Considerations for using low-sulphur fuel" by Michael Welsh Expert, Fuels and Lubricants Wärtsilä Switzerland Ltd, Winterthur of March 2002;
- Publication of Maritime Developments Advisory "Emission Control Area" under MARPOL Annex VI dated April 2009;
- MARTOB publication on "Operational aspects of a sulphur cap on marine fuels";
- Publication on the Mechanism of Metal Dusting Corrosion by C.M. Chun and J.D. Mumford Corporate Strategic Research Exxon Mobil Research and Engineering Company USA;
- MAN B&W Diesel's report on "Operation on Low-Sulphur Fuels Two-Stroke Engines";
- DNV paper on "Marpol 73/78 Annex VI - Regulations for the Prevention of Air Pollution from Ships - Technical and Operational implications";
- DNV publication "Low sulphur fuels - Properties and associated challenges" of December 2009;
- Intertanko / OCIMF publication – "Guidance for hazard identification for use of and switching to low sulphur marine gas oil in auxiliary boilers and associated equipment on board tankers" of December 2009;
- IVR's inland vessels database.