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POSSIBLE HAZARDS FOR ENGINES AND FUEL SYSTEMS USING HEAVY FUEL OIL IN COLD CLIMATE

RAMBØLL MARINTEK

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ACRONYMS, ABBREVIATIONS AND NOMENCLATURE

Acronyms, abbreviation, nomenclature	Description
API	American Petroleum Institute
Cat fines (CF)	Catalytic fines. Abrasive particles which may remain in the HFO after the refinery process
CEN	European Committee for Standardisation
CFR	Certified Flow Rate
Cn	Cetane number
cSt	centiStoke= mm^2/s. The unit of kinematic viscosity.
Cutter stock	A petroleum stock which is used to reduce the viscosity of a heavier residual stock by dilution
Destillate (fuel)	Distillate fuel is composed of petroleum fractions of crude oil that are separated in a refinery by a boiling or "distillation" process
FCC	Fluidized bed catalytic cracking
HCO	Heavy Cycle Oil
HFO	Heavy Fuel Oil
IFO	Intermediate Fuel Oil
IMO	International Maritime Organisation
Intermediate (fuel)	Mixture of distillate and residual fuel
LC(G)O	Light cycle (gas) oil
MARPOL	International Convention for the Prevention of Pollution from Ships (MARPOL) http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Prevention-of-Pollution-from-Ships-(MARPOL).aspx
MDO	Marine Diesel Oil. Fuel grade DMB: A general purpose fuel which may contain trace amounts of residual fuel and is intended for engines not specifically designed to burn residual fuels. It is generally designated as MDO.
MGO	Marine Gas Oil. Fuel grade DMA. A high quality distillate.
MDF	Marine Diesel Fuel. Distillate fuel grades are ISO-F-DMX, DMA, DMZ, DMB.
Residual (Fuel)	Residual fuel or "residuum" is the fraction that did not boil in a refinery process, sometimes referred to as "tar" or "petroleum pitch"
SOLAS	International Convention for the Safety of Life at Sea (SOLAS) http://www.imo.org/en/About/Conventions/ListOfConventions/Pages/International-Convention-for-the-Safety-of-Life-at-Sea-(SOLAS),-1974.aspx
Visbreaker	Processing unit in an oil refinery whose purpose is to reduce the quantity of residual oil produced in the distillation of crude oil and to increase the yield of more valuable middle distillates (heating oil and diesel) by the refinery

1 SUMMARY

This study has been carried out by Rambøll and MARINTEK on behalf of The Protection of the Arctic Marine Environment Working Group (PAME). The purpose of the study was to investigate possible hazards for engines and fuel systems using heavy fuel oil in cold climate.

One main aim of the project was to reveal whether ships that utilize heavy fuel oil in the Arctic will be overrepresented with respect to engine or fuel system failures, relative to comparable ships that utilize other fuel types.

The study address a general description of heavy fuel oil (HFO) based on general information from published sources. HFO characteristics and operational challenges related to HFO operation of ships are explained, and potential known risk factors related to HFO operation are discussed. Three main risk factors related to the fuel system have been identified which may cause engine failure or engine stop; Risks related to disruption of fuel supply; Risks related to fuel quality and Risks related to fuel switchover.

User experience with HFO operation has been collected from various sources such as insurance statistics, incident reports to US authorities, user interviews and coastal monitoring in Norwegian waters. Collected data were analysed to reveal any potential increased risk factors related to operation in cold climate.

- The result from interviews of chief engineer indicate that fuel switch problems do not occur more often, or that they are more frequent, in ships using HFO either in cold climate or in temperate zones.
- Today no additional requirements apply to the fuel oil systems for ships in arctic operation
- No relevant studies or data has been found indicating that low external temperatures increase the risk of engine failure during HFO operation.
- Fuel oil systems components are sheltered inside the ship and are heated by dedicated systems. During operation, the systems are not exposed to external environmental parameters as low air temperatures.
- Incidents related to fuel changeover as reported by USCG were not linked to cold external conditions
- Available data do not show any over-representation of HFO in drifting ship statistics from Norwegian waters.

HFO is the dominating bunker fuel for international shipping and has been used for decades. HFO is a blended product and is characterised by high density and high viscosity, and the industry has developed fuel standards to describe various HFO qualities. Operational challenges related to the use of HFO are well known and documented from insurance companies, classification societies and ship owners. HFO is a challenging fuel and needs proper storage, treatment and distribution system for safe operation in addition to good fuel management procedure on board the ship. When these factors are in place HFO is considered to be a reliable fuel for ships.

No findings in this study indicate increased hazards related to HFO operation in cold climate. On the other hand HFO operation needs careful attention by skilled personnel and good procedures to obtain safe operation. Off-spec fuel is probably the most important risk factor for engine failure or loss of propulsion, and effective On-board Fuel Management will significantly reduce the risk of engine break-down,lengthy/costly repairs or grounding.

It should be noted that the views expressed herein are those of the Rambøll and Marintek project team. As such the report should not be seen as PAME policy recommendations, but as information and advice from independent consultants.

2 INTRODUCTION

In this study the use of heavy fuel oil (HFO) as bunker fuel for ships has been elaborated. In the report general information on HFO operation has been provided, and potential increased risk for engine failure due to cold climate operation is discussed.

The study was financed by the Norwegian Maritime Administration on behalf of The Protection of the Arctic Marine Environment Working Group (PAME). PAME is one of six Arctic Council working groups and is the focal point of the Arctic Council's activities related to the protection and sustainable use of the Arctic marine environment.

Initially the specific properties of HFO, (i.e. HFO qualities and blends, trade names and terminology) are described and possible operation issues when used as ship fuel are discussed. This includes potential risk related to engine failure or enhanced probability for engine stop which could be related to the HFO characteristics. The provided descriptions have a general approach, but potential increased hazards for ship operation in cold climate and any added risk related for engine failure in such operations has been evaluated.

The study is based on general data on HFO operation and experience from ship owners, insurance statistics and incident reports to USCG and Norwegian authorities.

The potential connections between ship drifting and the risk of engine failure due to Heavy Fuel Oil (HFO) is illuminated by investigating data about drifting vessels available for the Norwegian Exclusive Economic Zone, Fishery Protection Zone around Svalbard and the Fishery zone around Jan Mayen. Events about drifting ships in these areas are logged by The Norwegian Costal Administration. An extract of the log is made available for this project. The analyses identify causes for drifting.

3 MARINE FUELS

3.1 Bunker Fuel Terminology

Crude oil, fuel oils and petroleum products are well known products and clearly defined in literature and standards. In this section a brief introduction and clarification of important terms and definitions are given based on the following references:

- http://www.kittiwake.com/fuel_terminology /1/
- A Master's guide to using fuel oil onboard ships, 2012, /2/
- Fuel Switching Advisory Notice, /3/
- Everything You Need to Know About Marine Fuels,2012, /4/

3.1.1 Composition and classification of crude oil

Crude oil is the basic source for all bunker fuels and is a mixture of many different hydrocarbons. The composition of crude oil can vary significantly depending on its source. Crude oils from the same geographical area can be very different due to different petroleum formation strata. Different classifications of crude oil are based on:

1. Hydrocarbons:
    - Paraffinic crudes
    - Naphthenic crudes
    - Asphaltenic (aromatic) crudes

   Each crude oil contains the three different types of hydrocarbons, but the relative percentage may vary widely. For example, there is paraffinic crude in Saudi Arabia, naphthenic crude in some Nigerian formations and asphaltenic crude in Venezuela.

2. American Petroleum Institute (API) gravity: The lower the density of the crude oil, the higher its API gravity. A higher API gravity means that the crude contains more valuable lower-boiling fractions.
3. Sulphur content: The ever-growing concern for the environment and the impact on refining cost calculations are the basis for this classification.
    - Sweet crude (low sulphur)
    - Sour crude (high sulphur)

3.1.2 Crude oil refining and stocks for marine fuel blending

Petroleum refineries are complex systems of multiple operations. The processes used at a given refinery depend upon the desired product slate[1] and characteristics of the crude oil mix. Today, complex refining has a definite impact on the characteristics of marine diesel and intermediate fuel oil (IFO) bunker fuel.

On average, crude oils consist of the following elements or compounds:

- Carbon – 84%
- Hydrogen – 14%
- Sulphur – 1 to 3% (hydrogen sulphide, sulphides, disulphides, elemental sulphurs)
- Nitrogen – less than 1%
- Oxygen – less than 1%
- Metals – less than 1% (nickel, iron, vanadium, copper, arsenic)
- Salts – less than 1% (sodium chloride, magnesium chloride, calcium chloride)

Crude oil is not used directly as a fuel in combustion processes, and before it can be used effectively it has to be refined. In an oil refinery a number of distillates are produced as petroleum, gas oil, kerosene, lubricating oils, heavy fuel oils and tar.

3.1.3 Heavy fuel Oil (HFO) and Intermediate Fuel Oil (IFO)

In the amendments to MARPOL annex I special requirements for the use or carriage of oils in the Antarctic area is defined, and the term "HFO" in this report is regarded to be equivalent with the characteristics as specified by the IMO:

- crude oils having a density at 15°C higher than 900 kg/m^3;
- oils, other than crude oils, having a density at 15°C higher than 900 kg/m^3 or a kinematic viscosity at 50°C higher than 180 mm^2/s; or
- bitumen, tar and their emulsions

Heavy fuel oil is a general term, and other names commonly used to describe this range of products include: residual fuel oil, bunker fuel, bunker C, fuel oil No. 6, industrial fuel oil, marine fuel oil and black oil. In addition, terms such as heavy fuel oil, intermediate fuel oil and light fuel oil are used to describe products for industrial applications, to give a general indication of the viscosity and density of the product.

Heavy Fuel Oil (HFO) is so named because of its high viscosity; it resembles tar when cold, and requires heating for storage and combustion. HFO's are used widely in marine applications such as main engines, auxiliary engines and boilers.

Bunker fuel has a variety of specification and for maritime application the following terms and definitions apply as described in Table 1:

[1] The ability of a refinery to vary its production of output

Table 1: Definition of bunker fuel types

Bunker fuel type	Description	Fuel Grades	Common Industry Name
Distillate	Distillate fuel is composed of petroleum fractions of crude oil that are separated in a refinery by a boiling or "distillation" process	DMX, DMA, DMB, DMC	Gas Oil or Marine Gas Oil
Residual	Residual fuel or "residuum" is the fraction that did not boil, sometimes referred to as "tar" or "petroleum pitch"	RMA-RML	Marine Fuel Oil or Residual Fuel Oil
"Intermediate"	Mixture of distillate and residual fuel	IFO 180, 380	Marine Diesel Fuel (MDF) or Intermediate Fuel Oil (IFO)

It is important to have knowledge of the bunker fuel terminology used in the marine industry;

- Distillate fuels are commonly called Gas Oil or Marine Gas Oil;
- Residual fuels are called Marine Fuel Oil or Residual Fuel Oil; and
- Intermediate types are called "Marine Diesel Fuel, (MDF)", or Intermediate Fuel Oil (IFO).

Heavy fuel oils are blended products based on the residues from refinery distillation and cracking processes. Different hydrocarbon structures' chain lengths have progressively higher boiling points, so they can all be separated by distillation. In the fractural distillation process in an oil refinery, crude oil is heated and the different chains are separated into the various components (called fractions) by their differing vaporization temperatures. Crude oil is heated, vaporized and then the vapour is condensed. (See Figure 1 for a simplified overview of this refining process).

Newer techniques use chemical processing on some of the fractions to make other fractions, in a process called conversion. Chemical processing, for example, can break the longer chemical chains into shorter ones. This allows a refinery to turn diesel fuel into petroleum, depending on the demand for petroleum. Refineries also treat the fractions to remove impurities.

Refineries combine the various fractions (processed and unprocessed) into mixtures to make desired products. For example, different mixtures of chemical chains can create petroleum with different octane ratings, and mixture of heavier components can make alternative fuel oil qualities.

The IFOs originate from the bottom product of the atmospheric distillation of crude oils and is also called the atmospheric residue. All IFOs have good ignition characteristics, due to the high percentage of paraffinic material still present in the atmospheric residue, and the paraffinic nature of the cutter-stocks used. The high amount of paraffinic hydrocarbons in the straight run marine fuels leads to relatively low densities for these products, ensuring easy and efficient on-board fuel purification.

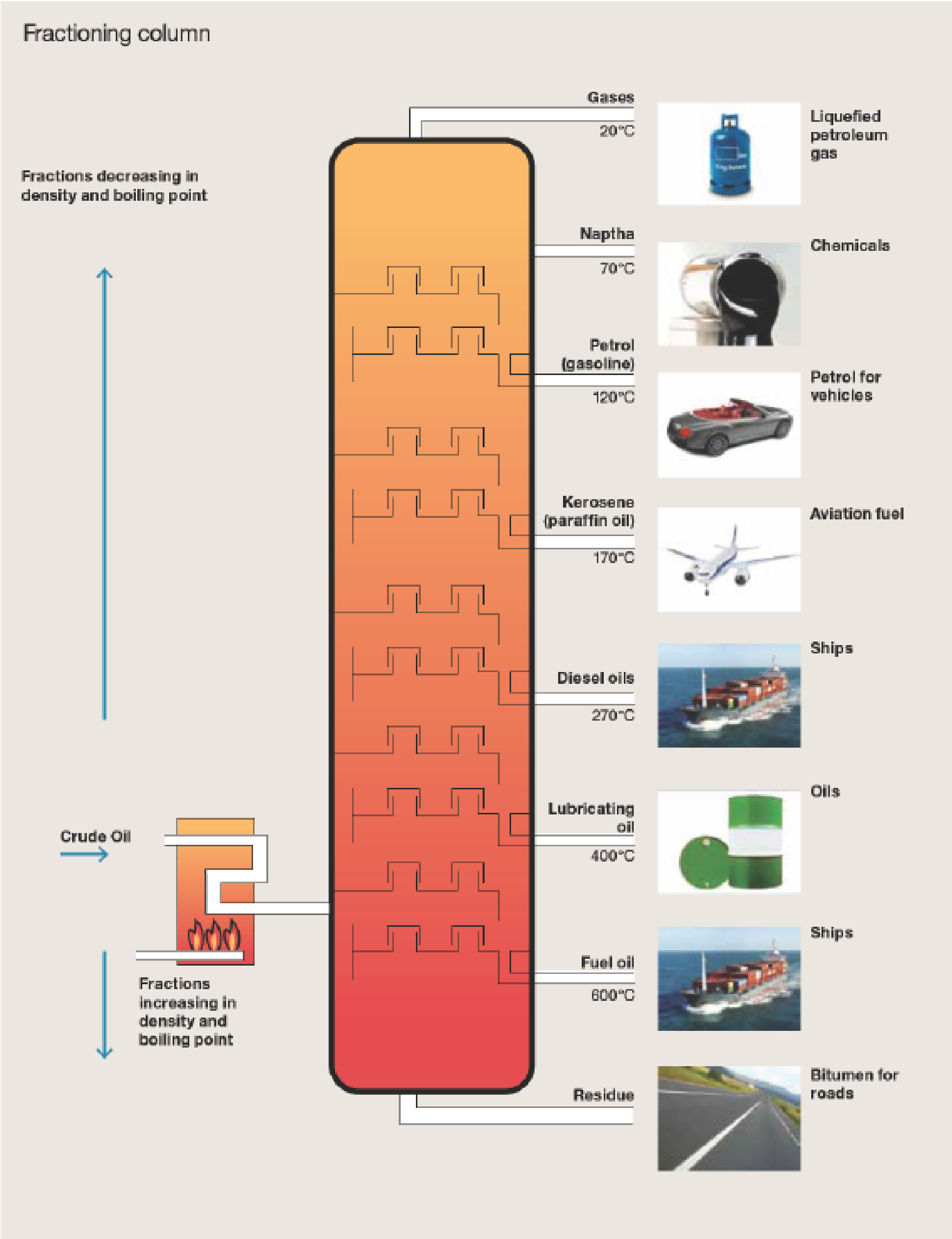

Figure 1 Fractional distillation, simplified overview of this refining process of crude oil. Source: The Standard P&I club, ABS: A Master's guide to using fuel oil on board ships, 2012

Secondary refining techniques, such as thermal cracking and catalytic cracking are commonly used to extract higher value products from crude oil. Thermal cracking uses a technique known as visbreaking[2]' to reduce the viscosity of the final residue. The result is that less cutter stock[3] is required to reduce the residue to its desired viscosity[4]. Visbreaking produces a lower quality residue, with a higher density, higher carbon content and poor ignition quality, /2/.

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[2] Visbreaking is a non-catalytic thermal process that converts atmospheric or vacuum residues via thermal cracking to gas, naphtha, distillates, and visbroken residue. Atmospheric and vacuum residues are typically charged to a visbreaker to reduce fuel oil viscosity and increase distillate yield in the refinery.

[3] A refinery stream used to thin a fuel oil or gasoil. Viscosity reduction and sulphur level adjustment provide most of the requirement for the cutter stock.

[4] Viscosity is the resistance of a liquid to shear forces (and hence to flow).

Catalytic cracking is perhaps the most important secondary refining process. Aluminium silicates are used as catalysts to further remove high value components, particularly gasoline. Heavy gas oils, or cycle oils, are also produced. These are often used as cutter stocks with visbreaking residues to produce residual fuel oils. The residue from the cracking process is termed 'slurry oil'. This slurry tends to be highly aromatic and of poor ignition quality, but can be blended with the final residual fuel oil. The catalyst components are expensive, and are therefore recovered. Some, however, can find their way into the end product (catalytic fines). As the name implies, residual fuel oil is produced from the residue of the refining process.

Catalytic fines remaining in bunkers are a major cause of damage to diesel engines and, this is one reason why fuel oil analysis is so important.

As a residual product, HFO is a relatively inexpensive fuel – typically its costs around 30% less than distillate fuels. It has become the standard fuel for large, slow speed marine diesel engines, this being especially so during the oil crises of the 1970s and 1980s. Its use required extensive research and development of the fuel injection system and other components of low and medium speed engines. HFO is still the dominating bunker fuel for international shipping.

3.2 Fuel Standards, /3/

3.2.1 ISO 8217

There are internationally recognized standards that define the characteristics of fuel oils and what they can contain so that they will be suitable for use on-board ships. The most widely used standard is ISO 8217 with the latest edition issued in 2012, see Appendix 1.

Other standards exist such as those issued by the Europe-based International Council on Combustion Engines (CIMAC), the British standard BS6843-1:1996 and the US standard ASTM D-975.

Frequently, the type of fuel that can be supplied to a ship is restricted to a fuel that meets a specific designation in one of the standards, usually from the ISO-8217 standard. The most commonly used HFO types are IFO180 and IFO380, where the number indicates the maximum viscosity in centiStokes (cSt) at 50°C. The highest viscosity fuel per ISO 8217 is HFO 700, but even though many ships have fuel systems designed to operate up to this viscosity, it is rarely actually used.

Sulphur content in the IFO180 and 380 fuels is currently restricted to 3.5 percent in Annex VI of MARPOL and this limit will progressively be reduced with time according to amended Annex VI.

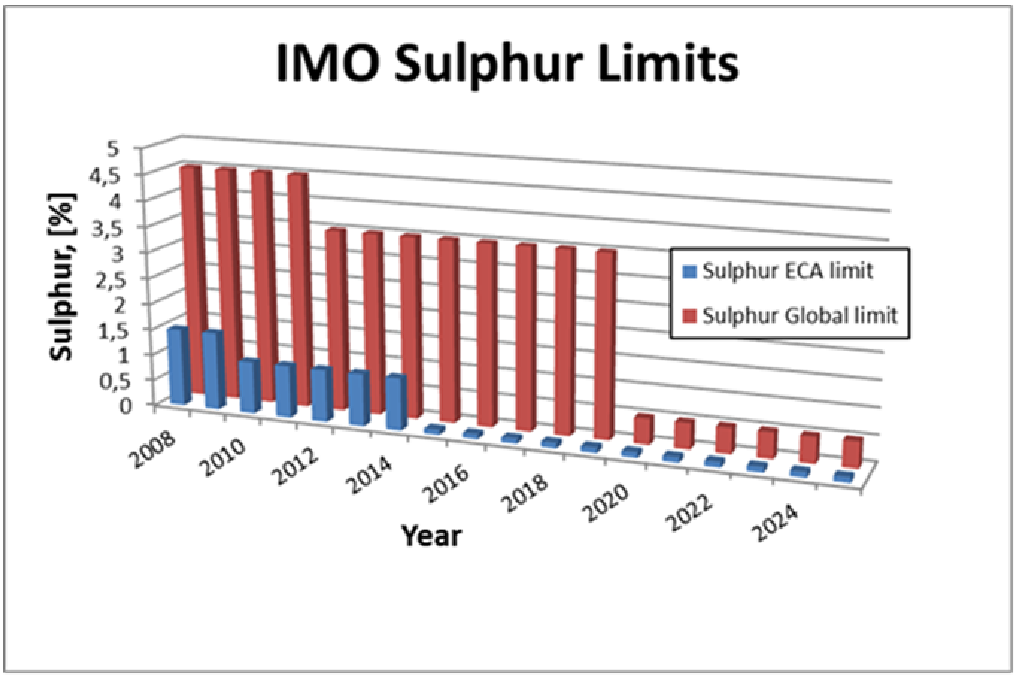


Figure 2:IMO MARPOL Annex VI - SOx emission limits, Source: IMO

From Figure 2 the global sulphur limitations are defined as follows:

- Global cap from 4.5% to 3.5% effective from 1. January 2012
- Global cap from 3.5% to 0.5% effective from 1. January 2020 (Depending on the outcome of a review, to be concluded by 2018, as to the availability of the required fuel oil, this date could be deferred to 1 January 2025).

Within Emission control areas (ECA) also designated SECA (Sulphur Emission Control Area) the following limits are defined:

- New sulphur limit from 1,5 % to 1,0 % effective from 1. March 2010
- New sulphur limit from 1,0 % to 0,1 % effective from 1. January 2015

In addition the following sulphur requirements for ships entering EU areas apply:

- Sulphur content limit 0,10 % by mass for ships at berth in Union ports
- Sulphur limit 1,5 % for passenger ships operating on regular services to or from any Union port until 1 January 2020.[5]

The marine distillate fuel designations per ISO 8217 are DMX, DMA, DMB and DMC. DMX fuel is a gas oil type fuel with low flash point (minimum 43°C). It is used only in special applications on ships since, for safety reasons, fuel with a minimum flashpoint of 60°C is the standard. All the other marine distillate fuels have a minimum flashpoint of 60°C. DMC is also not widely used as it is similar to DMB but with higher density and more impurities and so there is little demand for it. MDO is normally understood to mean fuel that meets the DMB standard and MGO is understood to mean fuel that meets the DMA standard.

The ASTM D-975 standard influence distillate fuels available in North America since most distillate fuels are consumed by automotive and land based engines and fuels sold into that market are prepared to meet one of the ASTM standard designations. The same fuels are sold to the marine market as meeting the closest ISO standard.

[5] DIRECTIVE 2012/33/EU

The most commonly used fuel made to an ASTM standard used on ships is No. 2 Diesel oil, which is similar to ISO 8217 Grade DMA. There are currently three standards for sulphur content in No. 2 Diesel, S15, S500 and S5000, where the number indicates the sulphur content in parts per million. In percentages, the sulphur contents are 0.0015 percent (also known as ultra-low sulphur diesel (ULSD)), 0.05 percent (low sulphur diesel) and 0.5 percent (regular diesel), respectively.

3.3 Marine Fuels - Summary

Today's high utilization of crude oils means that the HFO fraction is blended from visbroken residual oil and products from catalytic cracking (HCO /LCO). In cases where these blends do not meet the quality standards, cutter stock (higher quality distillates) is added.

The content of heavy cycle oils will increase the aromatic content with negative impact on ignition properties and compatibility with other bunker qualities (varies from producers and crude oil origins).

The fraction of impurities and content of unwanted metal-compounds will be significantly higher in HFO compared to crude oil (or residue from atmospheric distillation), due to higher yield of evaporated fractions (concentration of these elements in the remaining residue from the visbreaker).

Actual challenges related to operation on HFO:

1. Low Cetane number in HFO requires preheated engines. Cylinder units must be well maintained with good compression.
2. High content of aromatics in HFO (about 60%) increase the risk of instability when mixed with HFO from other sources or with light distillates. Formation of solid/semisolid particles (asphaltenes etc.) might occur with risk of fuel filters becoming clogged.
3. Cat Fines from catalytic cracking are usually present in HFO due to less than 100% recovery in refinery processes (Al –Si compounds). These particles are very abrasive. Content and size distribution must be monitored by fuel analysis, and must meet the conventional limit (60 ppm). High concentrations of large particles are likely to cause rapid wear of cylinder units and fuel pumps/injectors.

4 FUEL SYSTEM ONBOARD SHIP

4.1 Bunker tanks - design

Depending on vessel type, the bunker tanks are located as wing tanks or at the bottom of the hull. Current DNV rules (Enforced 2006) for fuel tanks require a min. distance of 0.76m to bottom of hull (moulded line) and 1.0 m from the side shell plating. In this way the fuel tanks should have similar protection as a double hull provides to its cargo (tankers). (Source DNV: New Regulation12A – Oil fuel tank protection; MARPOL 73/78 Annex 1).

Thus the bunker tanks are not directly exposed to sea temperature. At least 2 bunker tanks are required for ships using HFO To enable pumping to settling tanks, provision for heating to min 45 deg. C should be installed in the fuel tanks (heating coils). At this temperature HFO has a reasonable low viscosity, enabling transfer to settling tanks. Any water dispersion or impurities in the bunker tanks will eventually be transferred to the settling tanks.

The heating capacity should be designed to meet Class requirements, maintaining minimum 45 deg. C (DNV: Rules for Classification of Ships –Prt.6 Ch. 14).

Heat insulation should be used where heating capacity is marginal. New insulation materials/techniques allow the insulation to be placed on the walls inside the tanks which reduces heat loss to a minimum.

For older ships common designs and location of fuel tanks related to ship type was published by Intertanko in 2003, see appendix 2.

4.2 Internal fuel oil system

The design of the internal fuel system may vary from ship to ship, but every system should provide well cleaned fuel of correct viscosity and pressure to each engine. Temperature control is required to maintain stable and correct viscosity of the fuel before the injection pumps. Sufficient circulation through every engine connected to the same circuit must be ensured in all operating conditions. The fuel treatment system should comprise at least one settling tank and two separators.

Correct dimensioning of HFO separators is of greatest importance, and therefore the recommendations of the separator manufacturer must be closely followed. Poorly centrifuged fuel is harmful to the engine and a high content of water may also damage the fuel feed system.

Injection pumps generate pressure pulses into the fuel feed and return piping. The fuel pipes between the feed unit and the engine must be properly clamped to rigid structures. The distance between the fixing points should be at close distance next to the engine. A connection for compressed air should be provided before the engine, together with a drain from the fuel return line to the clean leakage fuel or overflow tank. With this arrangement it is possible to blow out fuel from the engine prior to maintenance work, to avoid spilling.

In multiple engine installations, where several engines are connected to the same fuel feed circuit, it must be possible to close the fuel supply and return lines connected to the engine individually. This is a SOLAS requirement. It is further stipulated that the means of isolation shall not affect the operation of the other engines, and it shall be possible to close the fuel lines from a position that is not rendered inaccessible due to fire on any of the engines.

4.3 Fuel heating requirements for HFO

In a HFO system external heating is required to handle the fuel properly and secure safe operation of the system. Heating is required for:

- Bunker tanks, settling tanks, day tanks
- Pipes (trace heating)
- Separators
- Fuel feeder/booster units

To enable pumping the temperature of bunker tanks must always be maintained 5-10°C above the pour point, typically at 40-50°C. The heating coils can be designed for a temperature of 60°C. Normally the heating is by way of steam produced by an oil-fired boiler and passed through coils inside the oil tank. Other ways to heat the fuel tanks are by using thermal oil.

The tank heating capacity is determined by the heat loss from the bunker tank and the desired temperature increase rate. Temperature control is required to maintain stable and correct viscosity of the fuel before the injection pumps.

Sufficient circulation through every engine connected to the same circuit must be ensured in all operating conditions. The fuel treatment system should comprise at least one settling tank and two separators. Correct dimensioning of HFO separators is of greatest importance, and therefore the recommendations of the separator manufacturer should be followed closely.

4.4 Settling tank, HFO and MDF

Separate settling tanks for HFO and MDF are recommended.

The fuel oil is first transferred from the bunker tanks to settling tanks for initial separation of sludge and water.

To ensure sufficient time for settling (water and sediment separation), the capacity of each tank should be sufficient for min. 24 hours operation at maximum fuel consumption. The tanks should be provided with internal baffles to achieve efficient settling and have a sloped bottom for proper draining.

The temperature in HFO settling tanks should be maintained between 50°C and 70°C, which requires heating coils and insulation of the tank. Usually MDF settling tanks do not need heating or insulation, but the tank temperature should be in the range 20-40°C.

From the settling tanks the fuel is transferred through the separators to the day tanks, from which fuel is supplied to the engines.

4.5 Day tank, HFO and MDF

Two day tanks for HFO are to be provided (Figure 3, 1T03), each with a capacity sufficient for at least 12 hours operation at maximum fuel consumption. A separate tank is to be provided for MDF. The capacity of the MDF tank (Figure 3, 1T06) should ensure fuel supply for 12 hours. Settling tanks may not be used instead of day tanks. The day tank must be designed so that accumulation of sludge near the suction pipe is prevented and the bottom of the tank should be sloped to ensure efficient draining.

HFO day tanks shall be provided with heating coils and insulation. It is recommended that the viscosity is kept below 140 cSt in the day tanks. Due to risk of wax formation, fuels with a viscosity lower than 50 cSt at 50°C must be kept at a temperature higher than the viscosity would require. Continuous separation is nowadays common practice, which means that the HFO day tank temperature normally remains above 90°C. The temperature in the MDF day tank should be in the range 20-40°C.

The level of the tank must ensure a positive static pressure on the suction side of the fuel feed pumps. In case of black-out, starting with MDF from a gravity tank is foreseen, then the tank must be located at least 15 m above the engine crankshaft.

5 FUEL TREATMENT

5.1 Separation

Heavy fuel (residual and mixtures of residuals and distillates) must be cleaned in an efficient centrifugal separator before it is transferred to the day tank.

Classification rules require the separator arrangement to be redundant so that required capacity is maintained with any one unit out of operation. All recommendations from the separator manufacturer must be closely followed. Centrifugal disc stack separators are recommended also for installations operating on MDF only, to remove water and possible contaminants. The capacity of MDF separators should be sufficient to ensure the fuel supply at maximum fuel consumption. If a centrifugal separator is considered to be too expensive for a MDF installation, then it can be acceptable to use coalescing type filters instead. A coalescing filter is usually installed on the suction side of the circulation pump in the fuel feed system. The filter must have a low pressure drop to avoid pump cavitation.

5.2 Separator mode of operation

The best separation efficiency is achieved when the stand-by separator is in operation all the time also, and the flow through the separator is reduced according to actual consumption.

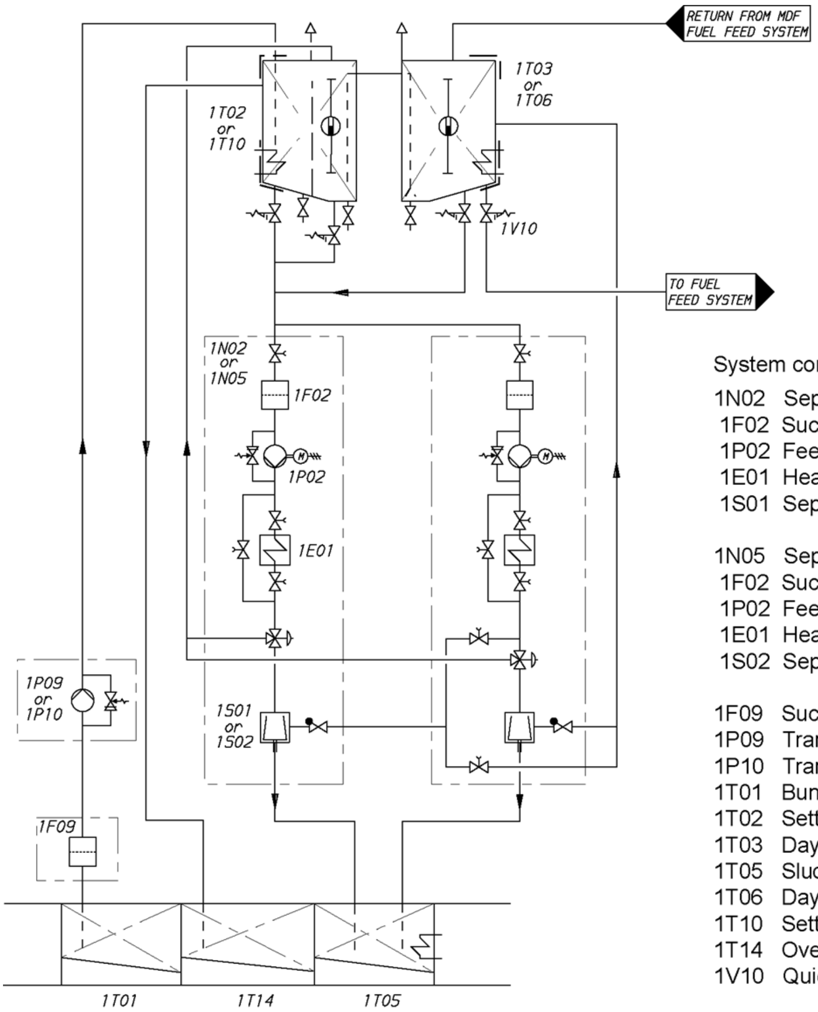
Separators with monitoring of cleaned fuel (without gravity disc) operating on a continuous basis can handle fuels with densities exceeding 991 kg/m3 at 15°C. In this case the main and stand-by separators should be run in parallel. When separators with gravity disc are used, then each stand-by separator should be operated in series with another separator, so that the first separator acts as a purifier and the second as clarifier. This arrangement can be used for fuels with a density of max. 991 kg/m^3 at 15°C. The separators must be of the same size.

5.2.1 Separation efficiency

The term Certified Flow Rate (CFR) has been introduced to express the performance of separators according to a common standard. CFR is defined as the flow rate in l/h, 30 minutes after sludge discharge, at which the separation efficiency of the separator is 85%, when using defined test oils and test particles. CFR is defined for equivalent fuel oil viscosities of 380 cSt and 700 cSt at 50°C. More information can be found in the CEN (European Committee for Standardisation) document CWA 15375:2005 (E). The separation efficiency is a measure of the separator's capability to remove specified test particles.

5.2.2 Fuel Oil System

A typical fuel oil transfer and separating system is shown in Figure 3



System components:

1N02 Separator unit (HFO)
1F02 Suction strainer
1P02 Feed pump
1E01 Heater
1S01 Separator (HFO)

1N05 Separator unit (MDF)
1F02 Suction strainer
1P02 Feed pump
1E01 Heater
1S02 Separator (MDF)

1F09 Suction strainer
1P09 Transfer pump (HFO)
1P10 Transfer pump (MDF)
1T01 Bunker tank
1T02 Settling tank (HFO)
1T03 Day tank (HFO)
1T05 Sludge tank
1T06 Day tank (MDF)
1T10 Settling tank (MDF)
1T14 Overflow tank
1V10 Quick closing valve (Fuel oil tank)

Figure 3: Flow diagram showing arrangement of settling/day tanks and separators. Source: Wärtsilä Engines

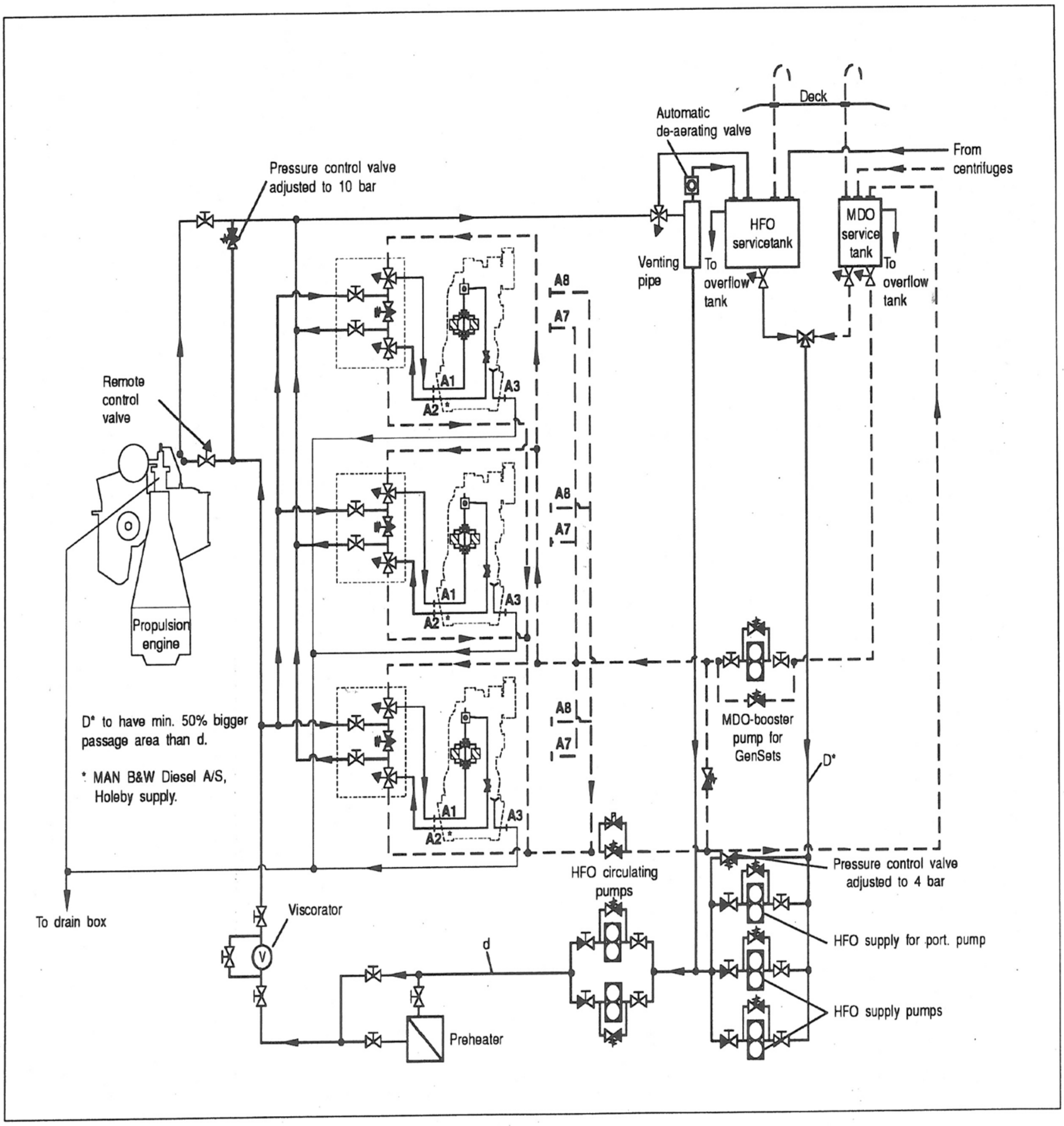


Figure 4: Fuel oil flow diagram showing conditioning of fuel oil to engines, designed with alternatives fuel qualities. Source: MAN Diesel and Turbo

The engine is designed for continuous operation on heavy fuel oil (HFO). Continuous operation on HFO is recommended as far as possible.

Engines with conventional fuel injection have a reducing valve in the fuel return line on the engine. The reducing valve ensures an even fuel flow through each engine. Engines with common rail fuel injection have a pressure control valve in the fuel return line on the engine, which maintains desired pressure before the injection pumps.

5.3 Fuel oil system and treatment - summary

The fuel oil system on board a ship consist of several tanks, piping and technical processing equipment to store, transfer and pre-treat the fuel in accordance with defined procedures and specifications. Pre-treated fuel is injected into and burned in the main or auxiliary engines to create propulsion power or electricity. The fuel oil system shall be designed and constructed in accordance with class regulations, and redundancy requirements apply.

For HFO, heating is required to keep the fuel above its pour point so it easily can be pumped through the system and so that it can be separated in the fuel pre-treatment system to remove impurities and water which are expected contaminations in the fuel. When the fuels leave the pre-treatment system it is stored in day tanks before it is transferred to the engine.

6 RISK OF ENGINE FAILURE OR STOP

6.1 HFO engines – characteristics

There is relatively little difference between HFO engines and engines running on MGO (marine diesel oil). For HFO operation heat tracing is put on fuel piping, including the high pressure injection pipe between injection pipe and nozzle. Heat tracing is needed to prevent cold HFO in the fuel circuit prior to starting. In normal ship installations, "heat tracing" of pipes (by steam or electric heating) can be turned on or off.

In the case temperature in the HFO lines are allowed to drop to ambient, the viscosity will increase significantly and circulation of HFO will be very slow (depending on viscosity class) until temperature reach about 50-60 °C. Cold 380 cSt oil is too thick for pumping.

HFO fuel injection nozzles are equipped with cooling bores circulation of cooling liquid (usually oil or water). Circulation and temperature control of cooling liquid is provided by an engine mounted system.

Cooling is needed to prevent overheating of the nozzle-tip and to avoid coke formation around nozzle bores. HFO Fuel temp is normally in the level of 130 °C (380 cSt) and the heat flux from combustion further increase nozzle tip temperature, which might lead to loss of hardness and lifetime of component. Coke formation on the nozzle tip is common with HFO combined with high nozzle tip temperature. Coke formation (sometimes referred to as coke-trumpets) interfere with fuel sprays, leading to exhaust smoke and increased fuel consumption.

Using HFO with high levels of vanadium and sodium might cause chemical erosion-damage at high surface temperatures. HFO engines are usually equipped with high grade exhaust valves (NIMONIC-alloys) to prevent valve-seat damages when operating on HFO.

6.2 Risk factors for engine failure or stop

Three main risk factors related to the fuel system has been identified which may cause engine failure or engine stop. These are:

1. **Risks related to disruption of fuel supply**

- Bunker storage, Settling tanks, Day-tanks. Fuel pipes. Fuel storage management
  - Temperature, Water drainage, sediment handling, cleaning
- Fuel conditioning (heating, cleaning, viscosity control)
  - Operation of separators, Procedures related to incompatible fuel oils

2. **Risks related to fuel quality**

- Remaining Cat-Fines in fuel oil
    a. Limits of Cat-Fines content, Operation of separators, Engine damages.
- Ignition and combustion quality
    a. Knocking combustion, Engine-fuel adaption, Engine damages.

3. **Risks related to fuel switch – over**

- Consistent procedure to maintain acceptable viscosity
- Engine - fuel system condition and maintenance.
    a. Worn fuel injection components - critical with low viscosity MGO.

Below is a brief discussion of the identified risk factors and relations to ship and fuel systems are further deliberated.

6.3 Risks related to disruption of fuel supply

6.3.1 Bunker Tank fracture

External incidents as collisions or grounding may lead to damage on the hull and consequently a risk for leakage and disruption of the fuel supply to the engine. Due to the minimum safety distance to the outer shell, an accident leading to puncture of hull will not lead to bunker-spillage unless the penetration goes quite deep and into the bunker-tank/tanks. This solution reduces the risk of spill significantly. I the case the ship becomes grounded the risk of HFO spill will to a large degree, depend on if the ship breaks up and where the bunker tanks are located. The middle section of the ship is then more likely to break and breach fuel tanks in this area. The cause of tank fractures may be collisions or groundings, but such risk factors are not considered to be within the scope of this report and are not further discussed.

6.3.2 Fuel pipes leakage

Internal leakage in fuel pipes or tanks may also cause reduced flow or disruption of fuel to the engine. Due to redundancy such incidents can be handled, and the damaged part of the system can normally be bypassed.

6.3.3 Loss of heating - Flow disruption

Loss of heating or flow disruption could be due to leakage of heating medium in heating coil, or in the circulating loop outside. An inside leakage means transfer to the standby heating coil which can be done by operating valves. In the case of a single heating coil, the oil temperature will slowly drop when the heater is switched off or fails. The temperature drops slowly due to the sheer mass of fuel, usually hundreds of tons (maximum permitted volume in one tank is 2500 m^3). Due to the requirement of minimum 2 tanks, the HFO supply can be switched over to additional tank for completion of voyage.

Disruption of HFO feeding from bunker tanks to settling tanks means that the operating time on HFO will be limited to the content of HFO in the settling tanks and the day tanks. This will be in the region of 2 times the operation on full engine power based on dual set of settling and day tanks (Class requirements) (24 + 12 hours). For further operation of the vessel a switch-over to MDO or MGO will be necessary in order to arrive at a port where repair to bunker heating system can be done.

6.4 Risks related to fuel quality

6.4.1 Incompatible fuels

It is advised not to fill new bunker oil into partly emptied tanks. This recommendation is based on possible risk of incompatibility. It is further advised to perform compatibility tests before starting the next voyage. In the case of confirmed incompatibility, a strategy or procedure should be followed to avoid large-scale mixing of fuels. The potential benefit will be less sediment production (asphaltenes) and less risk of having fuel-filters clogged up. It is worth noting that sediments formation due to incompatibility is a process that takes time and "aging" will usually increase the sediments.

6.4.2 Water and Sediments

The maximum sediment content is specified in the bunker fuel standard. A sediment-content up to 0.1 % is allowed for HFO (IF-380 - IF180). Allowable water is 0.5 %. These limits are relatively low, and are accepted by the users.

6.4.3 Cat fines

Cat fines (CF) are Al-Si compounds used as catalyst material in catalytic crackers (Table 2).
Engine damages found to be caused by HFO are mostly related to cat fines. Cat fines are small particles typically of size 10 - 50 micron. Engine manufactures recommend keeping the content of CF below 10 to 15 ppm, to prevent accelerated engine wear (higher than normal wear).

The current CF situation:

Table 2 Cat Fines in HFO

Cat Fines -Standards /recommendations	Concentration ppm
Fuel STD. permissible limit	Max. 60
Average in tested HFO	-30
Engine builders recommended limit	Max. 15

Based on reported engine damages, CF has been found to be the most frequent cause of fuel incurred damages.

Fuel sampling/analysis shows that CF content is normally below the limit of 60 ppm, and typically 20 -30 ppm on average (Cimac paper #51 -2013, /14/). However about 20% of the samples have shown concentrations in the range of 40 - 80 PPM. For efficient cleaning of bunker fuel, it is important to follow the manufacturer recommendations for separator operations regarding oil inlet temperature and oil flow. The total cleaning efficiency of cat fines should be at least 80 - 85%. There is a need for regular cleaning of the bottom of the settling tanks and day tanks due to settling of CF. New blends meeting Sulphur regulations in ECA's have shown an increasing trend in CF. Suggested explanation for this is that a larger portion of low sulphur products from cat-crackers are mixed into HFO such as slurry oil which might be classified as is a residue from catalytic cracking. However the content of CF in refined slurry oil is higher compared to catalytic cracking distillates (LCO and HCO), and is likely to increase the content of CF in blended HFO.

6.4.4 Settling tanks

The HFO systems are built in accordance with Rules and Regulations from Classification Societies as DNV-GL, ABS, etc. and class rules require two settling tanks in a vessel operating on HFO. The volume of each settling tank should be sufficient for 24 hours of operation. HFO transferred to settling tanks are passing through strainer-filters (0.5mm fineness) protecting the feed pumps. In the case of significant water content in fuel from the bunker tanks ending up in the settling tanks, these must be drained. Monitoring of settling tanks should be done on a regular basis and in particular after bunkering, to prevent large water accumulation in the tanks. The content of the tanks is run through separators and into the day tanks.

In these tanks sediments and cat fines will tend to sink, leading to higher concentrations at the bottom. To prevent higher concentrations of particles to reach the separator, the inlet of the suction pipe should be min. 500mm above bottom of tank. However, in rough sea inducing stirring in the settling tanks higher concentrations of impurities might enter the separators. As separators have a limited efficiency, the result might be that the purified HFO that goes to the day tank does not meet specified limits regarding Cat Fines and water.

6.4.5 Separators

The separator capacity shall be designed to maintain full engine power with one unit out of service. The separators (centrifugal) are designed to reduce content of harmful matter based on difference in gravity between fuel and impurities. With proper temperature (as high as practical, about 98 deg. C) water, sediments and Cat-Fines are separated from HFO. Settling tanks are heated to about 70 deg. C by internal heating coils, to get a practical viscosity for further processing, /15/.

6.4.6 Fuel to engine – conditioning system

6.4.6.1 Daytanks

A minimum of two day tanks shall be installed. According to class the volume of each day tank should be sufficient for 12 hours of operation.

HFO from settling tanks is heated to about 98 deg. C prior to entering the separator. High temperature is beneficial to increase the density gap between HFO and water. HFO exiting separators are fed into the day-tank. The content of the day-tank is ready for engine consumption and will be fed into the fuel booster- circuit. The inlet of the suction pipe leading to the separator should be minimum 500mm above the bottom of the tank. This is to prevent impurities/water accumulation to be fed into the booster-circuit.

6.4.6.2 Booster circuit

The purpose of the booster circuit is to feed the engine/engines with <u>clean</u> fuel with a <u>specified viscosity</u> and <u>pressure</u>. The pressure, usually in the range of 5-10 bar, will feed the injection pumps and minimize cavitation/vapour bubbles in the fuel pump rail. In the booster-circuit the fuel is heated to get correct viscosity and passes through a fine filter unit. This filter unit has 2 filters in parallel where one is normally in standby. Filters are equipped with monitoring, and an alarm will be triggered the case of filter is becoming clogged. In addition to the fine filters, a set of safety- filters are normally mounted on, or close to each engine as a back-up.

When particles accumulate in the filters, the flow becomes restricted and pressure across the filters increases. This triggers an alarm when it is required to replace filter inserts. To replace a filter-insert, oil-flow is switched over to the standby unit with a three-way valve for undisturbed engine operation. The clogged filter is opened and the filter inserts are replaced. The clean filter will now remain in standby.

In the case that the day-tanks become contaminated with particles due to poor separator efficiency or excessive sediments formation from incompatible fuels, the filters will usually clog up with shorter intervals than normal. A fuel switch-over to distillate fuel, will allow the daytanks to be run through separators until quality is restored.

Although mixing of incompatible fuels have the potential to produce sediments in the form of asphaltenes with potential risk of clogging filters, this has not been a widely reported cause of engines stopping.

The current HFO quality (visbroken residue mixed with HCO/LCO) has been the standard HFO mix for several decades, and such fuels are handled within the normal fuel management routines of the ship. However, if the ship receives off-spec fuel which is not detected during bunkering, incompatibility between HFO qualities may cause high sediment formation and operational problems.

6.4.7 Ignition and combustion of HFO

Current HFO, not straight - run but blended from, might contain a large fraction of aromatic hydrocarbons from LCO and HCO. These aromatics blending products have shown a very low Cetane index.

Tests of Cetane number (Cn) are standardized for distillates like auto-diesel and MGO qualities, however there is no conventional test for HFO blends. Equipment and tests are available, but the ignition properties are rated in a Cetane Index (The test equipment is different from the Cetane test engine).

Blended HFO might show a Cetane index ranging from 9 -20 (compared to Cn 53-45 for auto-diesel and MGO). Fuels at the lower end will burn with heavy knocking, particularly in 4-stroke engine at low to medium load. Knocking occurs when the fuel does not burn successively following injection (diffusion combustion), but with a significant ignition delay and with sudden rapid combustion of injected fuel (premixed combustion). Knocking combustion creates pressure peaks that are harmful to piston rings and bearing shells. New 4-stroke diesel designs meeting IMO NOx Tier II[6] requirements have significantly higher compression ratio compared to past design. This is necessary in order to maintain efficiency while meeting NOx emission standards. The current Tier II engines should be able to run on low cetane HFO without failure. Slow speed 2-stroke engine are less affected by low Cn. This is due to less injected fuel within the ignition delay period (less premixed combustion).

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[6] IMO requirment on NOx emissions from diesel engines

6.5 Risks related to fuel switchover

6.5.1 Fuel switch-over, system description

A fuel switch-over can be done by operating a simple 3-way valve, as shown in Figure 5. However, due to risk related to thermal contraction in fuel injection components, the procedure should be controlled by feedback to valve position base on permitted temperature gradient (max. 2 deg C/min). An automated Switch-Over system offers additional functions like data storage to verify ECA's regulation compliance etc.

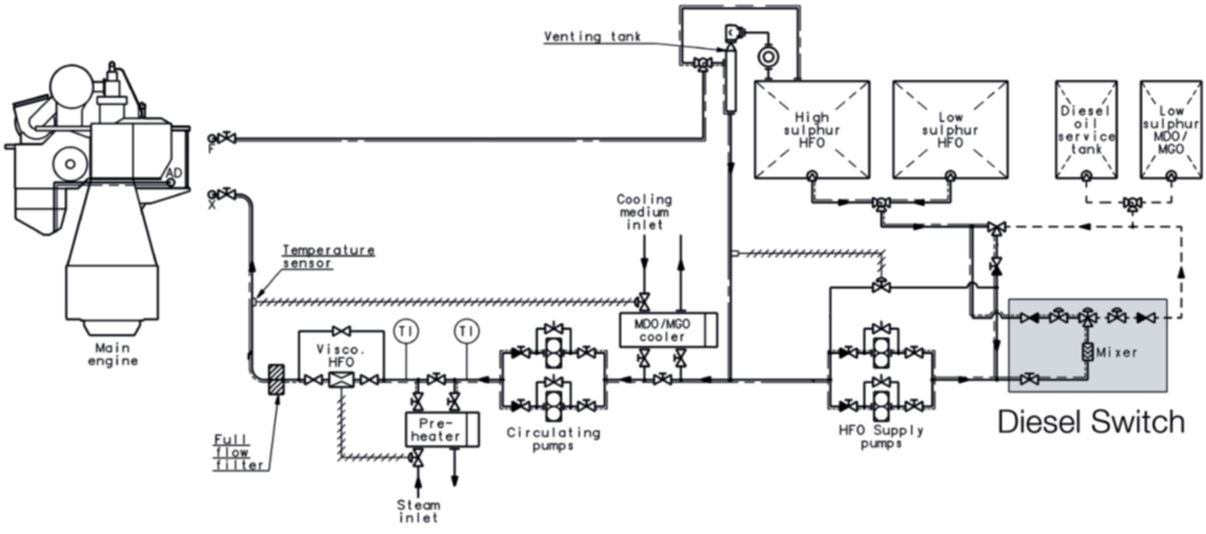

Figure 5: Fuel switch-over system implementation, (MAN Diesel)

Engine starting at berth on low sulphur MGO, should be done without a heated booster circuit to ensure an actual viscosity higher than 2.0 cSt. Engines which have had regular maintenance according to builder's manuals will start and run on MGO without problem. However, as previously mentioned, inadequate maintenance might cause a situation with excessively worn fuel pumps and too low fuel delivery for reliable starting with low viscosity MGO fuel.

6.5.2 Switchover description – potential faults

During fuel switch–over, the challenge is to maintain a viscosity within engine builder's requirements. Actual HFO viscosity to injection pump should be in the range 12 to15 Centistoke (cSt), and this is maintained by heating the HFO (380cSt) to about 130 deg. C. A sudden switch over to MGO might result in a dilution with high temperature and very low viscosity, less than 3 cSt. Low viscosity oil will have a higher leak rate in the injection pumps, causing reduced power output. In worn fuel pumps this might lead to large exhaust temperature deviation between cylinders which might trigger engine alarms. Fuel pumps are exposed to wear from CF and need regular maintenance with new plunger units and calibration. Operating the engine at low load is likely to give larger deviations in exhaust temperatures when viscosity is low and with worn pumps.

Quick changes in fuel temperatures is challenging due to small tolerances between the pump plunger and barrel. A significant temperature difference might lead to contact between the moving parts and with scuffing/seizure damage as result.
HFO dilution with MGO during switch-over might cause precipitation of asphaltenes, and it is important to monitor fuel filters during the process to detect any sudden increase in pressure drop. However the actual volume of mixed fuel is relatively small

and fuel incompatibility is usually confined to certain mixing ratio or range. This means that production of sediments will be limited to the switch-over duration time.

Switch over procedures are available from engine suppliers and automatic systems can be tailor made to the actual engine, taking into account fuel sulphur levels for ECA regulations.

If, for some reason, the engine stops during switchover, a restart might be challenging. During cranking the fuel rack is controlled by the engine control system and the pump delivery is limited to avoid excessive smoke. In a scenario with low viscosity and worn injection pumps the pre-defined starting setting might be too low for a successful start, due to internal fuel pump leakages. The remedy will be to override the fuel rack start setting, to get sufficient fuel injected for starting. However this has to be done by an experienced/trained engine operator. For a trouble free switch-over, it is essential to implement good maintenance procedures of fuel system components.

6.5.3 Additional information -Fuel switch over

Several parties have published information on Fuel switchover challenges, procedures and operational advice. Summaries from relevant sources are given below.

CIMAC /7/ has issued "Guideline for the Operation of Marine Engines on Low Sulphur Distillate Diesel". The objective of the document is to "advise the crew, users, vessel owners, charterers, crew, fuel and lubricant suppliers, equipment manufacturers, and classification societies about the fuel sulphur reduction options and implications, and especially the introduction of 0.10% m/m sulphur distillate in the ECA's from 1 January 2015. There are also general sections to provide information on legislation, economic implications, refining and supply considerations and operating vessels on lower sulphur fuel".

DNV GL/8/ has issued "Sulphur limits 2015 Guidelines to ensure compliance"**.** The document discusses regulatory background and important technical issues related to fuel change-over. This includes awareness of any risks associated with the change-over to avoid engine failure, power loss or even blackout. Further fuel properties and technical challenges as temperature change during the fuel switch, fuel incompatibilities, lower viscosity, lubricity, acidity and changed flashpoint are discussed.

Chevron Global Marine Products /4/ describes the challenges related to sediment in HFO and possible effects when blending fuel qualities as well as explanations related to fuel incompatibility . The refinery process, standards and fuel properties are also well described in this document.

6.6 Risk of engine damage or stop due to HFO operation- summary

HFO operation of ship engines involve several risk factors related to safe operation. Three main risk categories are discussed:

1. Risks related to disruption of fuel supply
2. Risks related to fuel quality
3. Risks related to fuel switch – over

Disruption of fuel supply can be caused by external leakage from bunker tanks due to hull damage (collisions, grounding), leakage on fuel pipes or malfunction or leakage in the fuel oil heating system. External causes as collision/ grounding is not considered to be within the scope of this report and is not discussed any further. Operation of the main engine is not dependent on continuous fuel supply from the bunker transfer system as day tanks have a capacity of operating the ship for 12 hours. So the main engine could still operate if the bunker fuel transfer system is shut off.

Fuel quality should be within specification. Off-spec fuel may cause severe operational problems. Proper fuel management is of vital importance for safe operation on HFO. This is highlighted by class and insurance companies. Incompatible fuel may cause sediments and sludge beyond acceptable values which may cause operational problems and filters to clog up. Impurities in the fuel such as cat fines and water need to be proper handled in the pre-treatment system using settling tanks and separators. To keep HFO at specified viscosity, heating is required, and heating coils/traces are installed in fuel tanks and pipes. HFO blends with high aromatic content have low cetane number resulting in poor ignition properties, which may cause heavy knocking during combustion and potential engine damage.

To secure safe operation during fuel switchover well established operation procedures is required. Fuel temperature and viscosity should be carefully controlled during this switchover. Engine manufacturer has established switchover routines which should be followed. Automatic switchover systems are on the market as well. Good maintenance procedures on the fuel oil system in general are important to avoid potential operational problems and special focus should be on the fuel injection components.

7 ENGINE DAMAGE AND LOSS OF PROPULSION

Limited statistics on engine damage and loss of propulsion caused by HFO operation is available. Statistics from insurance companies give a general overview of common claims related to engine damage. The USCG routinely tracks loss of propulsion incidents within US waters. Early in 2009 a subgroup for such incidents designated "Fuel switching related" was established to register loss of propulsion related to fuel changeover.

7.1 The Swedish Club

The Swedish Club provides members with a range of cover, including Protection and Indemnity (P&I), Freight Demurrage and Defence (FD&D), Marine & Energy and Ancillary covers and as of 1 September 2012, the Club had 1,041 vessels entered for P&I, 744 for FD&D and 1,484 for Hull and Machinery (H&M). A study on main engine damage was published by The Swedish Club in 2012, /5/ (ref Table 3, Table 4, Table 5, Table 6 and Table 7).

Table 3: The five most common types of claims (low speed engines), 1998-2004, /5/

Damaged parts	Number	Total cost (USD)	Avg. Cost (USD)
Turbocharger	63 (42.6%)	16,738,911 (40.7%)	265,697
Entablature	17 (11.5%)	4,174,652 (10.2%)	245,568
Cylinder liner	15 (10.1%)	4,537,317 (11.0%)	302,488
Bearing	9 (6.1%)	3,472,564 (8.4%)	385,840
Piston	7 (4.7%)	1,916,671 (4.7%)	273,810

Table 4: The five most common types of claims (low speed engines), 2005-2011, /5/

Damaged parts	Number	Total cost (USD)	Avg. cost (USD)
Turbocharger	114 (42.9%)	43,224,263 (30.7%)	379,160
Multiple parts	40 (15.0%)	28,928,107 (20.6%)	723,203
Cylinder liner	28 (10.5%)	11,660,199 (8.3%)	416,436
Bearing	14 (5.3%)	13,188,984 (9.4%)	942,070
Camshaft	12 (4.5%)	7,866,634 (5.6%)	655,553

Table 5: The five most common types of claims (medium speed engines) 1998 – 2004, /5/

Damaged parts	Number	Total cost (USD)	Avg. cost (USD)
Turbocharger	21 (25.6%)	3,484,729 (8.9%)	165,939
Crankshaft	21 (25.6%)	16,187,464 (41.5%)	770,832
Camshaft	8 (9.8%)	4,110,406 (10.5%)	513,801
Bearing	6 (7.3%)	4,450,079 (11.4%)	741,680
Fuel pump	5 (6.1%)	911,469 (2.3%)	182,294

Table 6: The five most common types of claims (medium speed engines) 2005 – 2011, /5/

Damaged parts	Number	Total cost (USD)	Avg. cost (USD)
Turbocharger	31 (29.8%)	6,597,091 (10.9%)	212,809
Multiple parts	25 (24.0%)	15,589,411 (25.7%)	623,576
Crankshaft	12 (11.5%)	13,557,133 (22.3%)	1,129,761
Cylinder liner	7 (6.7%)	7,729,750 (12.7%)	1,104.250
Piston	5 (4.8%)	2,109,023 (3.5%)	421,805

Cause of damage as analysed by the Swedish Club is as follows:

- Contaminated lubrication oil
- Not having experts attending major overhauls
- Using untested bunkers
- Separators not operated as per manufacturers' instructions
- Engine components not overhauled as per manufacturers' instructions
- Crew with insufficient experience/training
- Turbocharger damaged by foreign object

As can be seen from these results one of the main causes of damage is due to the bunker quality, but as described bad fuel quality is a known risk and extensive routines are recommended to avoid such problems. Most of the other causes of damage are related to operation routines and competence.

Table 7: Top 5 causes of damages , by number, /5/

Cause	No of claims	Avg. cost (USD)
Inferior maintenance and/or repairs	52	575,879
Lubrication failure	33	977,331
Foreign object	28	349,949
Off spec bunker	27	364,529
Latent defect	25	494,646

From published statistics by the Swedish Club, one of the causes to engine damage is related to off-spec fuel. Loss of propulsion due to fuel switch is not an issue in these statistics.

7.2 Fuel management

The Swedish club has done an in-depth investigation of multiple machinery claims which shows that a lot of engine damage is caused by off-spec bunker, and they argue that it is likely that this was avoidable or could have been minimized if proper On-board Fuel Management had been implemented and followed at all times.

The following issues are important:

- Effective On-board Fuel Management will significantly reduce the risk of engine break-down and lengthy/costly repairs. The components included in the fuel oil system are: bunker tanks, settling tanks, service tanks, various pumps, heaters, filters and separators.

By implementing and follow such routines the following benefits could be achieved:

- Avoid using untested fuel into ship machinery.
- Introduce tank cleaning and good routines to avoid sediment including cat fines which will accumulate at the bottom of the settling and service tanks to dislodge and clog filters, heaters and separators, which may occur in heavy weather.

The Swedish Club also conclude that dislodged cat fines could very quickly cause abnormal abrasive wear to various engine components, and over the years numerous “cat fine-related” damage to main engines resulting in towage and very costly and lengthy repairs have been registered.

7.3 GARD

Information provided by GARD /6/on fuel related claims 2010-2015 indicate that incidents caused by switchover have been very limited. It should be noted that the few incidents reported are quite unclear as to causation – i.e. reportedly the switch over have resulted in engine damages, but may in some cases be caused by inferior (off spec) fuel quality and not be related to the sulphur content. A total of 26 incidents were reported in the five year period, and from these only one was described as a switchover claim. The total tonnage insured by Gard is 211.000.000 GT (more than 12000 ships) so the issue of switchover from an insurance point of view may be regarded as negligible. However, Gard still calls for increased awareness regarding incompatibility between HFO and low sulphur distillates and practice during fuel changeover.

Most (but still few) of Gard incidents are however, related to off spec fuel which has been strongly addressed by the maritime actors. This is also in agreement with the Swedish Club study.

7.4 Loss of propulsion

One important issue related to fuel changeover is the possibility of loss of propulsion. As described, detailed operation procedures should be followed to ensure safe operation and several issues may lead to loss of propulsion during fuel changeover.

The California Air Resources Board (ARB) created regulations for vessel emissions reductions for California waters as part of its continued mission to improve air quality around the state. The new requirements came into effect in July 2009, under California Code of Regulations (CCR), Section 2299.2, Fuel Sulphur and Other Operational Requirements for Ocean Going Vessels within California Waters and 24 Nautical Miles off the California Baseline

The regulations require that vessels burn either marine gas oil (MGO) with maximum 1.5% sulphur, or marine diesel oil (MDO) with maximum 0.5% sulphur, in their main and auxiliary engines. Following the implementation of the regulations, California witnessed a 100 percent increase in loss of propulsion (LOP) incidents within state waters during 2009. In 2010, California saw 54 LOP incidents compared to 24 in 2008 as illustrated in Figure 6: Loss of propulsion incidents in US waters, 2009-2014, Source: USCG. (the last full year before ARB regulations took effect).

USCG has collected data from incidents in US waters related to Loss of propulsion. US data collected by the USCG has been presented and may give an indication of the severity of this problem.

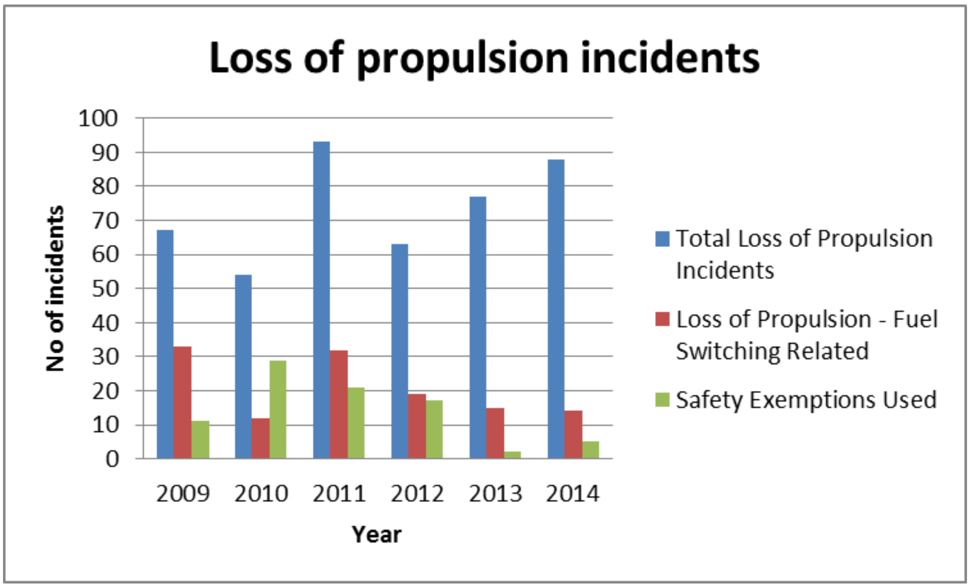

Figure 6: Loss of propulsion incidents in US waters, 2009-2014, Source: USCG.

From Figure 6 the reported "Fuel Switching related" incident count for approximately 16% of the total registered incidents in 2014. There is no information about the duration of the incidents or if they have led to further damage.

In 2011 The California Maritime Academy (CMA) evaluate issues associated with the implementation of the California Air Resources Board (ARB) ship fuel regulation, which began on July 1, 2009.Their findings was that some operators have reported operational difficulties that may be related to fuel switching from heavy fuel oil to distillate fuel. Such difficulties included shipboard issues as

1. Vessel stalling.
2. Variable engine speed at low loads.
3. Difficulty starting.
4. Inability to operate at full cruise speed.

The main cause of the reported difficulties was that heating of the distillate fuel resulted in viscosity below the recommended minimum level in combination with other factors as:

1. Worn fuel system equipment, such as fuel pumps or seals.
2. Engine adjustments not optimized for the use of distillate fuels such as rack or governor settings.
3. Operational procedures not optimized for the use of distillate fuel.

The use of a low viscosity distillate fuel combined with worn high-pressure fuel pumps resulted in inadequate fuel injection pressures. Loss of propulsion can result under these circumstances, due to excessive leakage of fuel within the high-pressure fuel pumps. Excessively worn or leaking pumps can result in low fuel injection pressures and incomplete combustion. Therefore, it is critical that shipboard crew maintain the fuel injection pumps within manufacturer's specifications, and ensure that fuel viscosity is maintained above 2 centistokes (cSt) at the high-pressure fuel pump inlet.

8 HFO OPERATION IN COLD CLIMATE

Ships operating in the Arctic climate are exposed to additional environmental loads due to poor weather condition and low temperatures. Low temperatures may influence on ship systems and their ability to operate according to specification. This is especially relevant for deck equipment and other systems directly exposed to cold temperatures and ice, and to a less degree for systems inside the ship. The special operating conditions in Arctic are also reflected in rules and regulations from IMO, classification societies and others, with special focus on material quality and strength issues to handle additional loads on the hull, propulsion system and appendages. Relevant rules and regulations are described in reference /9/and /12/.

The fuel oil system on board a ship is designed according to standards and regulations relevant for each ship type. The fuel quality and specification is essential to achieve safe engine operation at all times. Today no additional requirements apply to the fuel oil systems for ships in arctic operation but general design requirements apply as shown in DNV's Tentative Rules for Winterization (Table 8: DNV Rules, Pt.5 Ch.1 Sec.6 Tentative Rules for Winterization, /10/..

Table 8: DNV Rules, Pt.5 Ch.1 Sec.6 Tentative Rules for Winterization, /10/.

Item	*Object*	**Basic**	**Cold**	**Polar**	*Rule*
C309	Engine rooms – Re-start from dead ship		x	x	Functional requirements: — It shall be possible to re-start the main machinery from a dead-ship condition after 30 minutes under the design environmental conditions. Performance requirements: — The machinery shall be arranged such that it can re-start and operate from a dead-ship condition after 30 minutes at an outside ambient temperature 20°C colder than the design temperature (t_d). **Guidance note:** — Insulation may be necessary to ensure the machinery space maintains a sufficiently warm environment for re-starting the machinery after a dead- ship condition of 30 minutes. — Machinery may require air intake heating, cooling water heating and lube oil heating, depending on individual machinery specifications, to ensure it can re-start from a dead-ship condition after 30 minutes. — Water cooling lines and other machinery components that are subject to freezing should be located away from vessel sides, where they will getcoldest first.

In IACS "Requirements concerning POLAR CLASS", /11/, there are no particular requirements to the fuel oil system.

No relevant studies or data have been found that indicate that low external temperature increase the risk of engine failure during HFO operation. Fuel oil systems components are sheltered inside the ship and are heated by dedicated systems. During operation the systems are not exposed for external environmental parameters as low air temperatures. Incidents related to fuel changeover as reported by USCG was not linked to such external conditions

9 EXPERIENCES WITH FUEL CHANGEOVER SYSTEMS

9.1 Practical experience with fuel switch.

The International Maritime Organization (IMO), the governing body of international shipping, has made a decisive effort to diversify the industry away from HFO into cleaner fuels with less harmful effects on the environment and human health.

There has been an increasing global focus on the use of Heavy Fuel Oils the last decade. The predicted increase in activity in the Arctic areas, applying to the Oil and Gas industry and the shipping industry (due to the decreasing icecap in these areas), puts environmental issues on the agenda to a higher extent than earlier. The use of HFO and possible relations to incidents with loss of propulsion might be a part of the explanation for the focus on HFO.

In this part of the study shipping companies and engine producers were contacted, regarding possible interviews with personnel having practical experience with HFO and fuel shift. The goal was to be informed about experienced problems with the fuel switch process leading to engine damage, operational problems or loss of propulsion.

9.2 Method

Twenty shipping companies and three engine producers were contacted. We interviewed a group of five persons, each with longer experience than ten years as chief engineers on large ships using HFO. They also had extensive experience from different shipping companies, different ships, ship types and engines (Table 9), and they all had experience from both cold-, and more temperate climate.

Table 9 Types engines, ships and fuel types responders experience where based.

Engine types	Ship types	Type of HFO
Burmeister & Wain, (B&W)	Shuttle tanker	IFO 380
MAK	Bulk/Oil	380 cST
MAN B&W 7 50 MC	Cargo	
Sultzer 70 RTA and RTB	Tanker	
Daihatsu	Bulk Carrier	
Bergen Diesel	LPG Carrier	
STX	LNG Carrier	
Navara	VLCC tanker	

All persons except one are in different occupations today. All persons in the group were familiar with both manual and automatic fuel switch procedures, even though manual fuel switch seemed to be most common. In the interviews, the group was asked questions (appendix 3) related to fuel type and quality, operational problems, loss of propulsion, and challenges related to cold climate. The interviews were conducted by phone, one to one. The questions were sent by e-mail to the interviewees before the interview was conducted.

9.3 Findings

We experienced that the shipping companies were very much reluctant to talk to us about the use of Heavy Fuel Oil. This is probably related to both general cautiousness due to business, costs and can also be seen in the context of the climate discussions and the focus on using less pollutant and the potential harm to environment in case of spillage.

The companies contacted included owners of cargo ships, bunker ships, seismic surveys ships, container ships, offshore supply ships, tankers and cruise ships. We found that ships sailing in coastal areas, in the ECA, as well as most supply ships in the offshore industry use MGO or alternatives to HFO. The shift from one fuel to another is a complex process that is time consuming (described in chapter 5)and we might assume that ships sailing shorter distances will avoid the use of HFO. Bulk/cargo carriers, container ships and tankers use HFO and smaller ships (thumb rule smaller than 10 000 gross ton) do not usually use HFO. One of the engine producers also stated that their impression was that most cargo ships trafficking the coast of Norway and Svalbard now changed from HFO to MGO's.

The general impression is that HFO operationally is a very reliable fuel if routines of maintenance and the general recommendations from engine producers are followed. Maintenance of the engines running on HFO is in general more time-consuming than engines running on MGO. However the impression from the interviews is that most ships had good routines for regular maintenance and that the internal routines of the ships related to this often exceeded the recommendations from the engine producer. The interviewees were also experienced with changeover (switching) procedures, and had focus on training to minimize risks associated with fuel switch as referred to in chapter 6.

The group of interviewees was very much in sync with the descriptions of potentially risk of engine failure or stop as described in chapter 5. However, the results from the interviews suggest that risk of engine failure or stop, is not very high in general, and even less related to fuel switch. In cases where personnel had experienced engine operating problems these incidents could be linked to:

- Fuel quality
- Operational problems related to fuel switch
- Lack of maintenance and fuel system condition.

These areas are also described in chapter 6 and refer to existing literature and reports.

9.3.1 Fuel quality

The impression from the interviews was that fuel quality represents a large problem. The ships have however good routines for controlling the fuel quality. A drip test is used at each bunkering. The sample is collected throughout the whole bunkering. The report from the analysis together with the bunkers distributors' detailed specifications of the fuel is used to control the quality of the fuel. Most ships bunker from known and recognized distributors. There exists a "system" of "word of mouth" to avoid distributors with low fuel quality in the shipping industry. IFO 380 was the most common fuel in use in this investigation. All interviewees had experienced problems related to Cat-Fines and the importance of maintenance and routines were pointed out to avoid problems. Monitoring and adjusting the separation and filtration relative to the HFO bunkered is as important, as it is to know the content of the bunkered fuel. In the ECA areas only low sulfur HFO is allowed unless the ship has installed sulphur cleaning systems - usually scrubbers. Sulfur in fuels lubricates components in the fuel system and with lower sulfur content, the natural lubrication is reduced. Even though no one reported any incidents related to this, the focus on this was high in the group of persons interviewed.

9.3.2 Operational problems related to fuel switch

All personnel in the interview had experienced operational problems related to switch of fuel, and some had experienced engine stop during the procedure. In a few cases the stops were related to operational procedures during manual switches where routines and procedures were not followed.

Problems related to difference in temperature during a fuel switch (described in chapter 6.4) were reported in a few cases. This problem had in one case caused pump plungers to scuff.

Differences in temperatures were also reported to result in leakages of MGO in a few cases. However, this seemed to apply to worn fuel injection components, old engines and poor maintenance.

In cases where the engine stopped, although this was said to be rare, restart of the engine was described as especially challenging. Out in open waters restart could take up to one hour. Good practices and procedures, high focus on trained personnel, together with regular maintenance of filters and separators were pointed out as important follow-ups to avoid operational problems.

9.3.3 Lack of maintenance and fuel system condition

All persons interviewed had long and extensive experience with routines and procedures regarding maintenance, fuel quality and training of the crew. In this group we found that manual fuel switch is more common than automatic fuel switch, leading to high standards on personal performance and training. Knowledge about possible risks related to operating on HFO and fuel switch were high and procedures and routines, as described earlier, had higher standards than recommended by engine producers. None of the interviewees reported of specific incidents that could be directly related to lack of maintenance or fuel system condition.

9.3.4 Other operational problems

In one case the fuel filters were clogged by sludge due to heavy weather and "shaking" of fuel in the bunker tanks. None of the persons interviewed had experienced problems that could be related to cold climate. It was however pointed out that the use of distillate fuels due to low flashpoints potentially could cause problems in cold climate as the temperature in the fuel tank can decrease. The main opinion in this group was that fuel switch related problems did not happen more often in cold climate than in temperate climate.

9.4 Summary

The findings from the interviews indicate that there are few problems related to fuel switch in particular. There were however, few reports on engine problems related to the use of HFO in general. HFO was reported to be an operational reliable fuel. HFO is more demanding regarding maintenance although the impression is that engine procedures and routines are followed regularly, and often with higher internal standards and procedures than recommended. There is, and has to be, a high focus on fuel quality, with established procedures to analyze the type of fuel you are bunkering. This could potentially lead to reduced risk of engine problems. Incidents related to fuel switch were reported to be temperature related and in very few cases operational problems due to human factors. The interviewees represented a broad specter of shipping companies, ships and engines. The result from these interviews do not indicate that fuel switch problems occur more often, or are more frequent, in ships using HFO, either in cold climate or in temperate zones.

10 SHIP DRIFTING IN NORWEGIAN OCEAN AREA

The purpose of this chapter is to illuminate the potential connections between ship drifting and the risk of engine failure due to Heavy Fuel Oil (HFO). The analysis use data available for the Norwegian Exclusive Economic Zone, Fishery Protection Zone around Svalbard and the Fishery zone around Jan Mayen. Events about drifting ships in these areas might be logged by The Norwegian Costal Administration. An extract of the log is made available for this project.

10.1 Data about Ship Drifting in the Norwegian Administrative Area.

The Norwegian Coastal Administration's station in Vardø (VTS Vardø) monitor, in principle, the ship traffic in whole Norwegian Exclusive Economic Zone, the Fishery Protection Zone around Svalbard and the Fishery Zone around Jan Mayen. Positions reported via AIS are used. If a ship comes to rest without prior notice or a seemingly obvious reason, it is registered as a drifting event. The event is logged immediately after the ship has stopped. It ends when the ship is in motion again.

The ship is contacted immediately upon a registered stoppage. The ship is asked about the reason of stoppage, and whether it needs help. Ships, which stop within the territorial border of 12 nautical miles, may be required to accept a tug if there is a danger of the ship running aground. Ships which have stopped outside the territorial border, are only monitored. The monitoring is maintained for approximately ½ hour after the ship has established steady sailing.

The monitoring is performed to ensure that the ship is not drifting towards land. Therefore the coastal areas are a priority. But observations are also dependent on the coverage of AIS transponders on land and on platforms. In practice, this applies to a distance 40-50 nautical miles from the mainland, Bear Island and parts of Svalbard. In the North Sea the coverage is extended as a result of AIS transponders on platforms. Satellite-based AIS information is used only in rare cases. In some cases, incidents are also recorded as a result of a request from coastal radio or The Joint Rescue Coordination Centre.

Fishing vessels will often stop to do fishing. Such situations should not in principle lead to registration of ship drifting even if the stop is not notified in advance.

10.2 Data capture

From VTS Vardø, we have received reports of incidents in the period from the 1st of January 2011 till the 1st of November 2015, a total of 4.83 years. In this period there were 869 incidents recorded. For each event we have received information about these conditions:

- Name of the ship
- International Maritime Organization (IMO) number
- Time when incident was created in the log
- Time when the incident ended
- Comment on the cause of incident
- The ship's position

16 vessels are without available IMO numbers. For these it is not possible to link the information from databases with more information about the ships. These ships seem largely to be fishing and other small vessels, so it is of little practical importance for the analysis.

The comment on the cause of the incident is potentially the most interesting information. Unfortunately, a relatively small percentage of cases clearly described the cause of the stoppage. Either the cause is not available, or given a general problem description like "Machine Problems". Although the number of incidents is quite large initially, only a small part of the data is concrete enough to provide useful information. It is difficult to judge how representative this information is given how limited the useful dataset is compared to the total number of incidents.

Basically, the purpose is to find events which are caused by the use of HFO, or the switch between HFO and marine gas oil. This is not a relevant issue for small ships. Data from Ref.1 indicates that at the size of 5,000-10,000 tons (gross tonnage) the issue is relevant.

Each registered event of ship drifting is connected to a database for ship technical features for ships >3000 DWT. The source is from IHS ships database (IHS Sea-Web Database, http://www.sea-web.com). In addition, data obtained for all available ships registered in NOR and NIS is included in the database.

- IMO number
- Name of the ship
- Callsign
- Built, year
- Ship type
- Flag
- Deadweight (DWT)
- Gross tonnage (GT)
- Fuel Type 1
- Motor type
- Total motor power Kw
- Engine manufacturer
- Motor model

The information on the fuel type is considered so unreliable that it cannot be used in the analysis. It is therefore tonnage or engine power which must be selected to identify potential users of HFO. We have chosen to use 10,000 tons GT as a limit. Ref. /16/.

10.3 Main results of registered incidents

The comments contained in the data are grouped into cause category. Table 10 summarizes the events of the main groups.

Table 10 Causes of identified drifting ships in the Norwegian Exclusive Economic Zone 2011-2015. All observations.

Incident type	Numer of incidents 2011-2015	Average number of incidents per year	Percent of total
Anchoring	1	0,2	0 %
Other cause	1	0,2	0 %
Black-out	10	2,1	1 %
Fuel problems	8	1,7	1 %
Ship accident	12	2,5	1 %
Engine problem, specified	43	8,9	5 %
Engine problem, unspecified	146	30,2	17 %
Engine stop	42	8,7	5 %
Net/rope in propeller	9	1,9	1 %
Planned maintenance	62	12,8	7 %
Engine repair	57	11,8	7 %
Towing	7	1,4	1 %
Unknown cause	471	97,4	54 %
Total	869	179,8	100 %

Many events are relatively well described. But two major groups are without a specific description. This applies to the groups "Engine Problem unspecified" and "Unknown cause". These constitute 71% of the total number. It is not always clear what specific repairs were needed even for events indicated as repair of machine. Replacing the fuel pipes/pump is often stated, but the reasons for this are not further described. In most cases there is not given any description of the causes of engine failure. HFO, as directly or indirectly causing the ship drifting, may only be excluded in about 17% of the cases.

“Unknown cause” events make up 54%, while in 46% of cases the cause is partially known. Various forms of engine problem are the most common, accounting for 75% of the known causes of ship drifting. Problems associated with fuel make up only 2%. Of these, one case is due to the switch from HFO. Thereby, one specific case constitutes 0.2% of incidents with known causes.

For 667 of the events we are able to identify the ship. Table 11 contains the results based on ship type.

It is necessary to distinguish between scheduled events where maintenance, for example filter replacement, obviously belongs to the category. Repairs can be scheduled, while black-out, engine failure and engine trouble are obviously not scheduled events. Unscheduled events account for 70-80% of total events with stated cause, depending on whether repairs are included or not.

Table 11. Ship drifting incidents 2011-2015 distributed by ship type

Type of ship	Engine problems	Accidential engine stop	Maintenance and repair stop	Other cause	Unknown cause	Total
General cargo	65	16	47	3	144	275
Specialized cargo ships	7	2	10	0	25	44
Container ship	2	1	1	1	16	21
Ro-ro cargo	2	0	0	0	3	5
Bulk carrier	17	3	15	1	63	99
Oil and chemical	7	0	2	1	25	35
Gas tanker	7	0	2	1	18	28
Other tankers	19	10	21	0	55	105
Passenger ships	5	4	0	0	9	18
Offshore Vessel	0	0	0	1	2	3
Service ships, Tugs	7	2	0	1	5	15
Fishing	8	4	0	2	5	19
Total	146	42	98	11	370	667

The three largest groups are cargo ships, chemical and product tankers and bulk carriers. Passenger ships, offshore vessels, fishing vessels and other ships are in practice not registered with data about the ship since they are largely less than 3,000 GT. This is the main reason why the table only contains 667 of the 869 recorded incidents.

10.4 Frequency of incidents

It is interesting to examine whether specific types of vessels are particularly vulnerable to ship drifting incidents. It requires knowledge of exposure that is most accurately measured by the number of ships kilometres for the various ship groups in relevant waters (see Table 12).

We have not been able to calculate sailed ships distance in the waters that VTS Vardø monitors. However, in the report "Ship Accidents and risk level in Norwegian Waters" prepared by Ramboll for the Norwegian Costal Administration in 2014, /17/, there is an estimate of distance sailing for the same types of ships within Norwegian Exclusive Economic Zone, Fishery Protection Zone around Svalbard and the Fishery Zone around Jan Mayen. This covers more than the VTS Vardø observed area, but is assumed to provide a relatively good picture of the total ship sailing distances. The areas outside the coverage area is geographically large, but with fairly little ship traffic.

Table 12. Frequency of ship drifting in the Norwegian Exclusive Economic Zone 2011-2015. Distributed by ship types.

Vessel type	Average vessel km per year	Number of drifting incidents total	Average number of drifting incidents per year	Number of drifting incidents per mill vessel km
General cargo	16 441 764	275	73	4,5
Specialized cargo ships	1 723 663	44	12	6,8
Container ship	1 041 203	21	6	5,4
Ro-ro cargo	1 128 895	5	1	1,2
Bulk carrier	4 245 641	99	26	6,2
Oil and chemical	2 497 019	35	9	3,7
Gas tanker	1 367 006	28	7	5,5
Other tanker	4 310 843	105	28	6,5
Passenger ships	14 232 829	18	5	0,3
Offshore Vessel	4 750 590	1	0	0,1
Other ships	5 701 596	15	4	0,7
Fishing	13 612 953	19	5	0,4
Total	71 054 002	665	177	2,5

Table 12 shows the yearly frequency of incidents for different types of ships. 202 events with ship drifting are not included in the calculation of frequencies. Most of these events are ships less than 3,000 DWT, including fishing vessels, believed to be a significant group. It would hardly be correct to distribute events without known ship type in the same proportion as those with known ship type. Therefore we have chosen to ignore these.

Distance sailed includes data for the entire Norwegian Administrative Area. This area includes the Norwegian Exclusive Economic Zone and Fisheries Protection Zone around Svalbard. In practice, this is a large part of the North Sea, North Atlantic and Barents Sea west of Russia. However, with the exception of the North Sea, data do not contain events with ship drifting farther from the coast than about 40 nautical miles. In addition, this ratio indicates too low number of incidents in the calculation of frequencies.

With some exceptions, we assume that the table gives a relatively good picture of how often ships drift, and a better picture of differences between various types of ships. It is interesting to note that there is relatively little difference in frequency for different cargo ship groups. Ro-ro cargo is the only type of cargo ship which stands alone with a lower frequency than the others.

Bulk carriers, gas tankers and other tankers are registered with about half the distance sailed outside 24 Nm. General Cargo ships have most of their distance sailed within 24 Nm from coastline. Key figures for the number of operating vessels per million ship km is probably most appropriate for general cargo ships, while probably somewhat low for the other cargo ship types.

Passenger ships, offshore vessels, other ships and fishing vessels have a significantly lower number of incidents per million ship km. Figures for passenger ships are dominated by domestic ferries, about 9 million ship km as well as speedboats and Hurtigruta with about 4 million ship km. Cruise ships and international ferries

represent approximately 1 million ship km. Most of the sailing takes place inside the coastal sea boundary. Key figures for the number of events with ship drifting should therefore be quite correct for passenger ships, but probably too low for fishing vessels. Most passenger ships are registered in the Norwegian national registry and thus included in recorded incidents while fishing vessels, either Norwegian or foreign, are not included.
According to re1 1 HFO IN THE ARCTIC-PHASE 2, HFO is used in most ships larger than 10,000 GT. A significant percentage of vessels between 5,000 and 10,000 GT also uses HFO. Passenger ships, off-shore ships, fishing vessels and ships in the group "Other activities" makes little use of HFO. These are also the ship groups that are identified with the lowest number of ship drifting incidents per million ship km. However, these ships have other sailing patterns than those most common for cargo vessels.

Passenger ships are relatively frequent in port, usually many times per day. Fishing vessels and Off-shore ships are also relatively often entering ports. Repairs and maintenance for these vessels would normally be performed in port. Passenger and offshore vessels have redundancy in mechanical systems with several main engines, whereby a simple error in the machinery does not mean that the vessel will be drifting. Because of these differences in sailing patterns and other differences, it is difficult to argue that low frequencies of ship drifting are based on limited use of HFO in these vessels. However, it cannot be excluded that there is a causal relationship at work here. Further investigation is needed in order to conclude.

10.5 Duration of events

Most events registered last only a relatively short period. Of 869 events, 100 had a duration of one hour or more. 22 had duration of 3 hours or more. In most cases, the ship will start sailing without danger to the ship or others, and without assistance of any kind. In about half the cases, the ship started after 10 minutes or less (Figure 7).

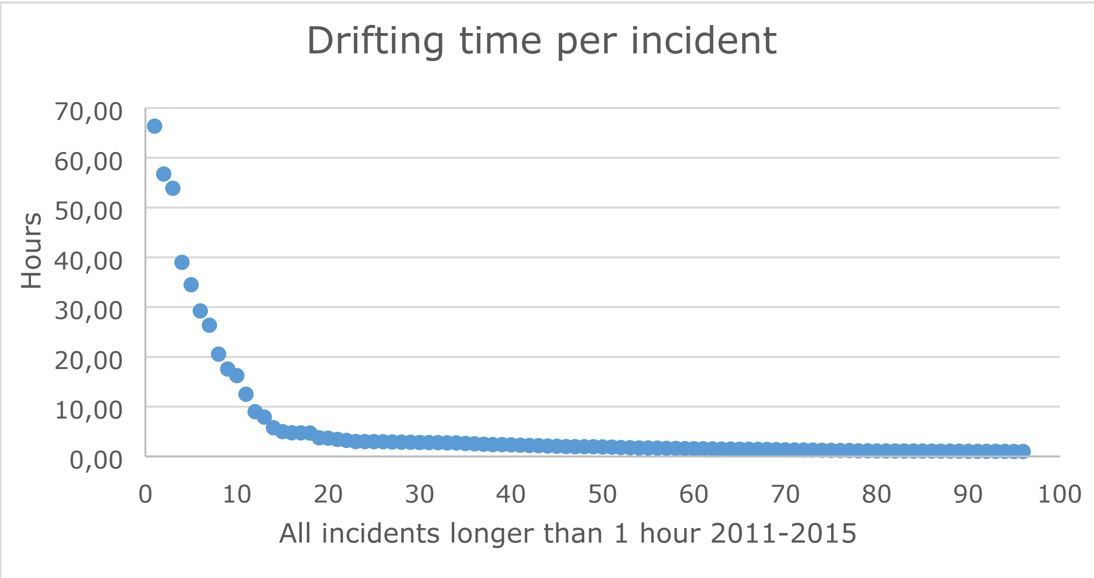

Figure 7. Duration of event with ship drifting. All with longer duration than 1 h.

Ten out of 869 events have lasted for longer periods of ½ day or more. The comments do not give information about the specific cause, but oral information from VTS Vardø indicates that at least some of these situations are caused by piston maintenance work on vessels located far from land.

10.6 Incidents in the Arctic

Of 869 events of ship drifting in 5-year period 2011-2015, 9 have occurred in the Arctic, all in the waters around Svalbard. All incidents have been with smaller ships, smaller than about 400 tons, these have nearly all been fishing vessels or passenger ships. One larger vessel incident was registered, namely a Russian research ship at 1,259 tons DWT. The ships involved in incidents around Svalbard, have clearly not been using HFO.

10.7 Incidents involving large ships

Large ships are those believed to be able to use HFO, where they are larger than 10,000 tons GT as the limit.

Table 13 compared to Table 10 shows more or less a similar distribution of various drifting causes for large ships compared with that for the total. The large ships believed to be able to use HFO, constitute a little more than 1/4 of the total number of drifting ships with known ship size (667) (Table 14).

Table 13 Causes of ship drifting larger than 10,000 DWT. Events 2011-2015 with known ship size.

Cause	Total	Percent of total
Black-out	2	1 %
Fuel problems	1	1 %
Ship causalities	2	1 %
Engine problems, specified	10	6 %
Engine problems, unspecified	27	15 %
Engine stop	4	2 %
Planned maintenance	17	10 %
Repair of engine	8	5 %
Unknown cause	105	60 %
Total	176	100 %

Table 14 Ship drifting larger than 10,000 GT distributed on ship type and reason. Incidents 2011-2015 with known ship size.

Cause	General cargo	Container ship	Bulk carrier	Oil and chemical	Gas tanker	Other tankers	Offshore Vessel	Total
Black-out						2		2
Fuel problems			1					1
Ship causalities		1		1				2
Engine problems, specified			3	4	1	1	1	10
Engine problems, unspecified	3		11	2	1	8	2	27
Engine stop			2			2		4
Planned maintenance	1		4	2	1	9		17

Repair of engine	1		7					8
Unknown cause	6	8	51	16	3	21	0	105
Total	11	9	79	25	6	43	3	176

10.8 Incidents caused by fuel

A fuel problem is logged as the reason for seven incidents. One of these refers to the change between HFO and MDO upon approach to the Norwegian coast. There are also three cases of fuel leakage, one caused by water in the fuel tank and two with a fuel supply problem. Some cases of fuel filters being changed are recorded as maintenance. Quite a few cases are explained as the changing of fuel pipes/pumps.

10.9 Summary - HFO as the cause of the ship drifting

The presented data shows the many reasons why ships may drift. NCA Vardo shipping control record barely 200 drifting vessels per year in the Norwegian Exclusive Economic Zone, the bulk of these along the coast of Norway and in the North Sea. In about 1/3 of the recorded cases of ship drifting, the ships have had such a size that the use of HFO may be relevant.

In most cases, where drifting ships are recorded, the ships are on their way again after a short pause, in 90 % of the cases, within one hour and in 97% of cases, within three hours.

If a ship operates within the territorial border, the NCA Vardo shipping control is entitled to require towing. This is done when there is a danger of the ship running aground. It is therefore unlikely that a ship would drift on to land. The risk of running aground is nonetheless present, if an incident occurs close to the coast. For ships sailing more than 12 nautical miles away from the coast, there should be sufficient time to implement a rescue. Thus running aground in such a situation represents a small risk. Traffic separation schemes are established along the coast of Norway. The consequence being ship traffic using routes further away from the coastline.

In 46% of cases, there is some significant information about the reason for the ship drifting. Most common the cause is engine problems of various kinds. In 24% of cases, the descriptions are so concrete that HFO might reasonably be excluded, with the exception of one case where change of HFO is cited as the reason. "Unknown reason", "Engine stop" and "engine problems, unspecified” accounted for 76% of the cases. It cannot be excluded that HFO may be part of the causal chain for some of these incidents.

In the last 5 years in the Arctic, there have been registered episodes of ship drifting, but none with such a size that HFO is the applicable fuel. There has been an average of 2 incidents per year in areas around Svalbard, with the vast majority of episodes involving fishing vessels. The present data indicate that ship drifting with HFO hardly represents an issue of importance in Svalbard.

Most of the situations involving ship drifting are due to acute faults, most commonly engine problems of some kind. In most instances, the ship was on its way again within a short period of time without assistance from other vessels. The issues on board are generally addressed without causing danger of any kind. Use of HFO might be the cause of individual cases of drifting ships, but this classification is related to a select few when the cause of the ship drifting is clearly stated.

10.10 Incidents reported to insurance companies.

Serious marine incidents may cause economic claims to insurance companies. As described in chapter 6, the major causes to engine damage has been identified, and offspec fuels is among the top 5 causes to damage which is fuel related. However, from the statistics presented above a direct link to offspec fuel is indicated in only one incident linked to fuel problems where HFO/MGO switch-over was identified as the cause. Seven out of 869 drifting incidents are reported caused by fuel problems. However, since fuel problems might cause other engine problems, the subsequent engine problem might be the reported cause. If ships drifting in Norwegian waters are reported and investigated in more detail in the future, it should be possible to answer this question.

10.11 Follow up

Data involving drifting ships in the Norwegian Administrative Area can give good information about drifting causes. But the present dataset has barely enough information to provide a basis for further in-depth analysis. The dataset would be better suited for thorough analysis, if information was registered in a more structured manor. This could most easily be accomplished by changing the routinely applied questions used by VTS Vardo. More detailed questions about the cause when the ships were contacted should be formulated such as to provide a more detailed dataset regarding specific causes for stoppages. Otherwise it is possible for VTS Vardø or others to follow up with detailed questions after the event, but this would need to be as soon as possible so as to maximise the chances of receiving the proper level of detail. Regardless, it will not be possible to get better answers than those the responsible party on the ship concerned is willing to give. There is good reason to believe that a conscious commitment to better data collection regarding the causes of ship stoppages, can give better data for analysis when implemented for as little as a year or two.

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APPENDICES

MARINE FUELS
EXTRACT FROM PAPER
QUESTIONS FOR INTERVIEWS

APPENDIX 1. MARINE FUELS

Distillate marine fuels

Characteristic		Unit	Limit	Category ISO-F- DMX	DMA	DMZ	DMB	Test method reference
Kinematic viscosity at 40 °C[a]		mm²/s	max.	5,500	6,000	6,000	11,00	ISO 3104
			min.	1,400	2,000	3,000	2,000	
Density at 15 °C		kg/m³	max.	—	890,0	890,0	900,0	see 7.1 ISO 3675 or ISO 12185
Cetane index		—	min.	45	40	40	35	ISO 4264
Sulfur[b]		mass %	max.	1,00	1,50	1,50	2,00	see 7.2 ISO 8754 ISO 14596
Flash point		°C	min.	43,0	60,0	60,0	60,0	see 7.3 ISO 2719
Hydrogen sulfide		mg/kg	max.	2,00	2,00	2,00	2,00	see 7.11 IP 570
Acid number		mg KOH/g	max.	0,5	0,5	0,5	0,5	ASTM D664
Total sediment by hot filtration		mass %	max.	—	—	—	0,10[d]	see 7.4 ISO 10307-1
Oxidation stability		g/m³	max.	25	25	25	25[e]	ISO 12205
Carbon residue: micro method on the 10 % volume distillation residue		mass %	max.	0,30	0,30	0,30	—	ISO 10370
Carbon residue: micro method		mass %	max.	—	—	—	0,30	ISO 10370
Cloud point		°C	max.	–16	—	—	—	ISO 3015
Pour point (upper)[c]	winter quality	°C	max.	—	–6	–6	0	ISO 3016
	summer quality	°C	max.	—	0	0	6	ISO 3016
Appearance		—	—	Clear and bright[h]			d, e, f	see 7.6
Water		volume %	max.	—	—	—	0,30[d]	ISO 3733
Ash		mass %	max.	0,010	0,010	0,010	0,010	ISO 6245
Lubricity, corrected wear scar diameter (wsd 1,4) at 60 °C[h]		µm	max.	520	520	520	520[g]	ISO 12156-1

a 1 mm²/s = 1 cSt.
b Notwithstanding the limits given, the purchaser shall define the maximum sulfur content in accordance with relevant statutory limitations. See Annex C.
c Purchasers should ensure that this pour point is suitable for the equipment on board, especially if the ship operates in cold climates.
d If the sample is not clear and bright, the total sediment by hot filtration and water tests shall be required, see 7.4 and 7.6.
e If the sample is not clear and bright, the test cannot be undertaken and hence the oxidation stability limit shall not apply.
f If the sample is not clear and bright, the test cannot be undertaken and hence the lubricity limit shall not apply.
g This requirement is applicable to fuels with a sulfur content below 500 mg/kg (0,050 mass %).
h If the sample is dyed and not transparent, then the water limit and test method as given in 7.6 shall apply.

Residual marine fuels

Characteristic	Unit	Limit	Category ISO-F-											Test method reference
			RMA	**RMB**	**RMD**	**RME**	**RMG**				**RMK**			
			10[a]	**30**	**80**	**180**	**180**	**380**	**500**	**700**	**380**	**500**	**700**	
Kinematic viscosity at 50 °C[b]	mm²/s	max.	10,00	30,00	80,00	180,0	180,0	380,0	500,0	700,0	380,0	500,0	700,0	ISO 3104
Density at 15 °C	kg/m³	max.	920,0	960,0	975,0	991,0	991,0				1010,0			see 7.1 ISO 3675 or ISO 12185
CCAI	—	max.	850	860	860	860	870				870			see 6.3 a)
Sulfur[c]	mass %	max.	Statutory requirements											see 7.2 ISO 8754 ISO 14596
Flash point	°C	min.	60,0	60,0	60,0	60,0	60,0				60,0			see 7.3 ISO 2719
Hydrogen sulfide	mg/kg	max.	2,00	2,00	2,00	2,00	2,00				2,00			see 7.11 IP 570
Acid number[d]	mg KOH/g	max.	2,5	2,5	2,5	2,5	2,5				2,5			ASTM D664
Total sediment aged	mass %	max.	0,10	0,10	0,10	0,10	0,10				0,10			see 7.5 ISO 10307-2
Carbon residue: micro method	mass %	max.	2,50	10,00	14,00	15,00	18,00				20,00			ISO 10370
Pour point (upper)[e] winter quality	°C	max.	0	0	30	30	30				30			ISO 3016
Pour point (upper)[e] summer quality	°C	max.	6	6	30	30	30				30			ISO 3016
Water	volume %	max.	0,30	0,50	0,50	0,50	0,50				0,50			ISO 3733
Ash	mass %	max.	0,040	0,070	0,070	0,070	0,100				0,150			ISO 6245
Vanadium	mg/kg	max.	50	150	150	150	350				450			see 7.7 IP 501, IP 470 or ISO 14597
Sodium	mg/kg	max.	50	100	100	50	100				100			see 7.8 IP 501 IP 470
Aluminium plus silicon	mg/kg	max.	25	40	40	50	60				60			see 7.9 IP 501, IP 470 or ISO 10478
Used lubricating oils (ULO): - calcium and zinc; or - calcium and phosphorus	mg/kg	—	The fuel shall be free from ULO. A fuel shall be considered to contain ULO when either one of the following conditions is met: - calcium > 30 and zinc > 15; or											see 7.10 IP 501 or IP 470 IP 500

a This category is based on a previously defined distillate DMC category that was described in ISO 8217:2005, Table 1. ISO 8217:2005 has been withdrawn.

b 1 mm2/s = 1cSt.

c The purchaser shall define the maximum sulfur content in accordance with relevant statutory limitations. See 0.3 and Annex C.

d See Annex H.

e Purchasers shall ensure that this pour point is suitable for the equipment on board, especially if the ship operates in cold climates.

Designation of Marine products

Marine products or grades are designated by a symbol consisting of a group of letters which together constitute a code. This code consists of:

a) the initials "ISO"; for the International Standardization Organization
b) the letter "F" for the class of fuel;
c) the category of fuel, consisting of three letters:
    1) the family letter, "D" for distillate or "R" for residual,
    2) "M", designating the application "Marine",
    3) a letter, e.g. "A", "B"…"Z", which taken separately has no significance, but has meaning in relation to the particular properties in accordance with the product specification, ISO 8217:2010;
d) a number that corresponds to the maximum kinematic viscosity of the residual fuel, in square millimeters per second (mm^2/s) at 50°C.

In the ISO standard, within each viscosity class of fuel, there are subcategories, such as RME 180, RMF 180 and RMH 380, RMK 380, etc. The fuels with a last letter early in the alphabet have lower density and fewer impurities (and would generally cost more).

A product or grade may be designated in the complete form or in an abbreviated form, e.g. : ISO-F-RMG 380 or RMG 380.

A complex refinery processing scheme can be separated into two parts:

1. Crude oil distillation (atmospheric and vacuum distillation)
2. Streams from the vacuum distillation unit are converted through catalytic and thermal cracking processes.

Complex refineries have been favoured since the early 1980s and are designed to boost gasoline production. The main marine fuel blending components from a fluidized bed catalytic cracking (FCC) refinery with visbreaker are the same distillates as those from a straight run refinery (light and heavy diesel). Addition fractions are light cycle (gas) oil (LC(G)O) and heavy cycle oil (HCO) from the catcracker and visbroken residue from the visbreaker.

Marine gasoil (MGO/DMA/DMZ)

A new blend component has appeared — light cycle (gas) oil [LC(G)O]— that contains about 60% aromatics. Due to the high aromatic nature of LC(G)O, the density of a marine gasoil blended with LC(G)O will be higher than when using gasoil from an atmospheric distillation refinery. The density will typically be close to 860 kg/m^3 (at 15°C). No performance or handling differences with atmospheric gasoil are to be expected.

In 2010, the fourth edition of ISO 8217 standard introduced an additional grade of marine gasoil, DMZ, which has a higher minimum viscosity than DMA but is otherwise identical in its characteristics to DMA marine gasoil.

11.1.1 Distillate marine diesel (MDO/DMB)

Distillate marine diesel (commercial denomination) typically has a lower cetane index than marine gasoil, and has a higher density. With the production slate (i.e. the ability of a refinery to vary its production of output) of a catalytic cracking refinery, distillate marine diesel can therefore contain a higher percentage of LC(G)O than marine gasoil.

IFO-380

This grade is usually manufactured at the refinery and contains visbroken residue, HCO and LC(G)O. These three components influence the characteristics of the visbroken IF-380. Vacuum distillation reduces the residue yield to about 20% of the crude feed, unavoidably leading to a concentration of the heaviest molecules in this fraction. Visbreaking converts about 25% of its vacuum residue feed into distillate fractions. This means that about 15% of the original crude remains as visbroken residue. The asphaltenes[7], sulphur and metal content in visbroken residue are 3 to 3.5 times higher than in atmospheric residue. Visbreaking affects the molecular structure:

- molecules are broken thermally, and this can deteriorate the stability of the asphaltenes.

HCO (typical viscosity at 50°C: 130 mm^2/s) contains approximately 60% aromatics, and is a high-density fraction: the density at 15°C is above 1 kg/l (typically 1.02). It is the bottom fraction of the FCC unit. The catalytic process of this unit is based on aluminium silicate. Some mechanical deterioration of the catalyst occurs in the FCC process, and the resulting catalyst fines are removed from the HCO in the refinery. This removal, however, is not 100% efficient and a certain amount (ppm level) of cat fines remains in the HCO. From there they end up in heavy fuel blended with HCO.

The aromaticity of HCO assists in ensuring optimum stability for the visbroken fuel blend. LC(G)O (typical viscosity at 50°C: 2.5 mm^2/s) has the same aromaticity as HCO, but is a distillate fraction of the FCC unit, with a distillation range comparable to that of gasoil. With a typical density of 0.94 kg/l at 15°C, it is used to fine-tune the marine heavy fuel oil blending where generally a density maximum limit of 0.9910 kg/l has to be observed.

IFOs < 380 mm^2/s

In ISO 8217:2010, blended marine diesel known as DMC has been reclassified as a residual fuel oil, RMA10. With atmospheric refining, RMA10 can contain up to 10% IFO with either marine gasoil or distillate marine diesel. With complex refining, RMA10 no longer corresponds to a specific composition and extreme care must be used when blending this grade to prevent stability and/or combustion problems. The other low viscosity residual fuel oil grades are generally blended starting from 380 mm2/s IFOs (at 50°C), by using a suitable cutter-stock (marine diesel, gasoil, LC(G)O, or a mixture of these). The blend composition has to be constructed in such a way that the product stability is safeguarded, while at the same time direct or indirect density limits are fulfilled.

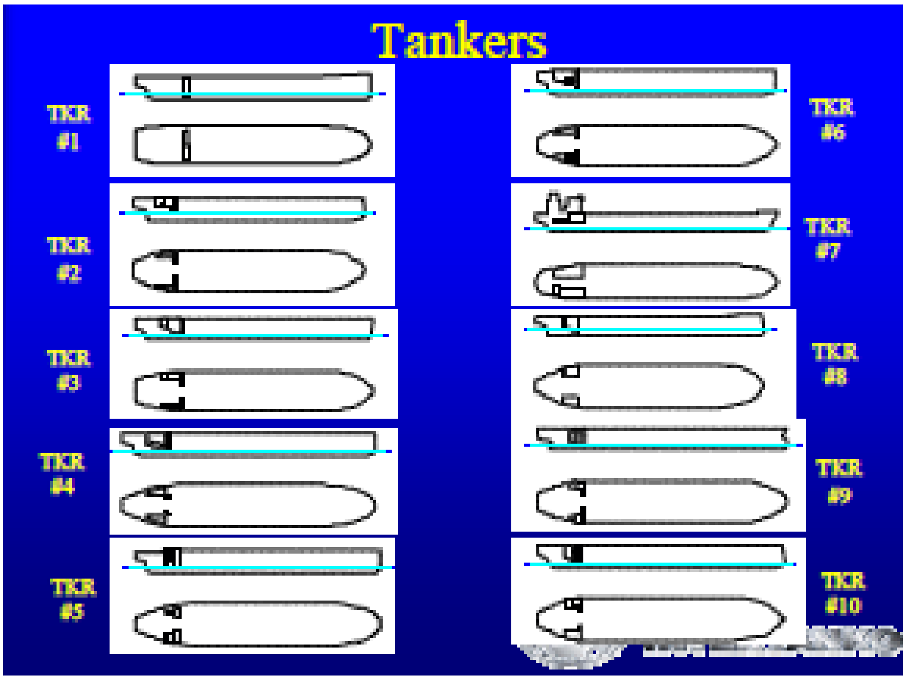
[7] Asphaltenes: residual fuel components that are insoluble in heptane but soluble in toluene

APPENDIX 2 - EXTRACT FROM PAPER

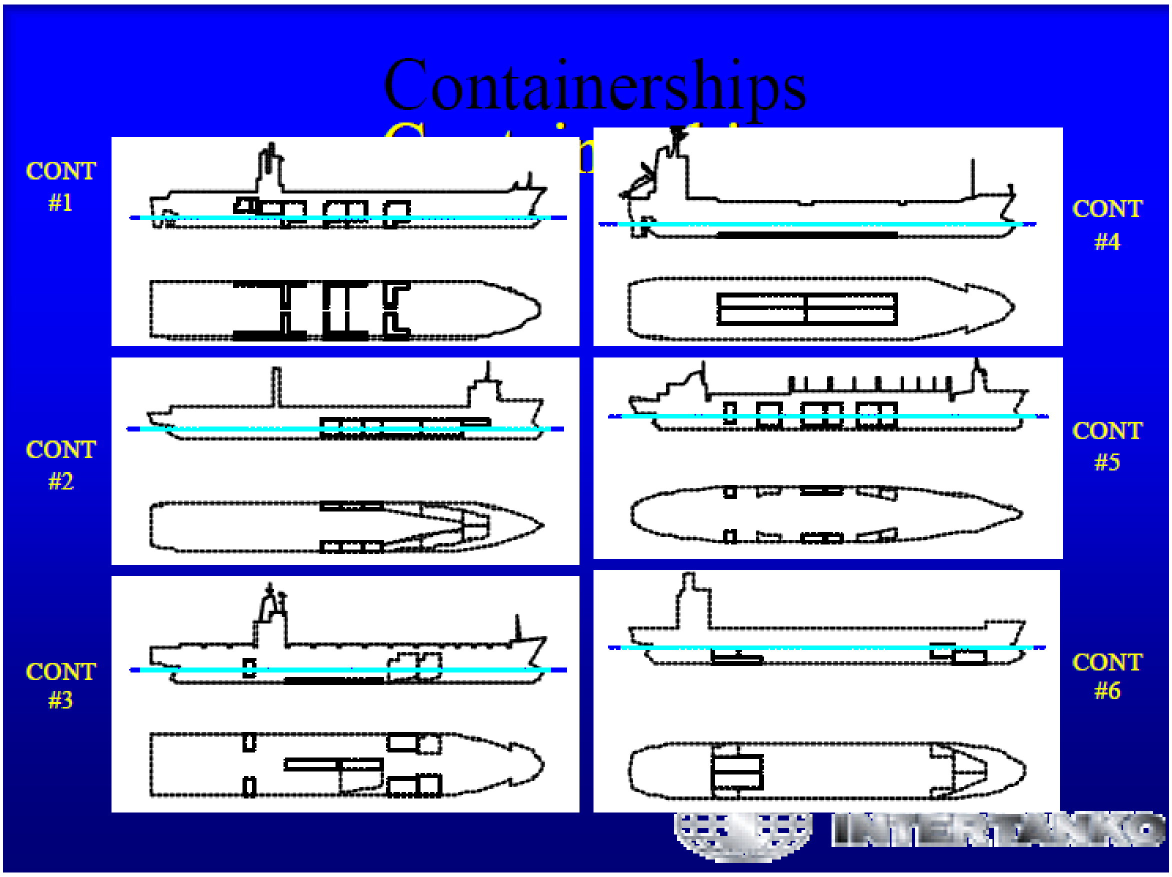
Protection of Bunker Tanks
The 24th International Bunker Conference, Rotterdam, 9th May 2003
Dragos Rauta, INTERTANKO

Standard Design Practices
The vessels are representative of the wide variety of bunker tank arrangements currently in
service. Design considerations lead to different bunker tank arrangements for different ship
types.

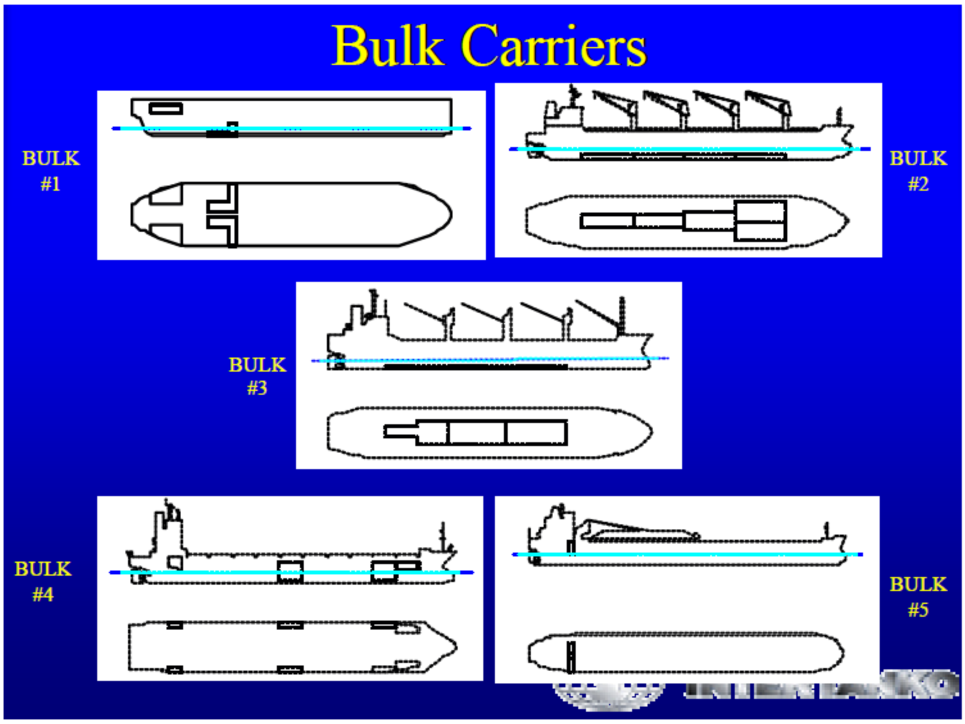
- Tankers: The HFO tanks are usually arranged in one or two pairs of wing tanks (see arrangements T1 and T2). This allows for short piping runs, and avoids passing HFO piping through ballast and cargo tanks. The double-hulled spaces forward of the engine room are dedicated to cargo oil, maximizing cargo cubic.



- Containerships: Typically, the majority of HFO is allocated to wing tanks outboard of the cargo holds. These tanks are distributed longitudinally through the midship region, such that bunkering or consuming fuel oil does not significantly alter trim or stability (see C1). Additionally, there will be some bunker oil storage in engine room wing tanks.



- Bulk Carriers: Capesize bulk carriers usually carry their fuel oil in engine room wing tanks similar to tankers. For the smaller Handysize or Panamax ships, HFO is most commonly allocated to center double bottom tanks. Alternatively, bulk carriers may have HFO in the outboard double bottom/ing tanks, or arranged in deep tanks forward together with engine room tanks (see B1).



The table below summarizes typical capacities for HFO and DO tanks for various sizes of tankers, containerships, and bulk carriers. The high-powered post-Panamax containerships have the largest HFO storage requirements, with the total HFO capacity for recent newbuildings exceeding 7,600 m^3 (2 million gallons). The HFO is usually distributed in a number of wing tanks, such that the capacity of any one tank does not generally exceed 1000 m^3 (264,000 gallons). In comparison, VLCCs have tanks as large as 3,400 m^3 (898,000 gallons), as the HFO is typically allocated to one or two pairs of ER wing tanks.

Tankers

Description	Panamax	Aframax	Suezmax	VLCC
DWT (MT)	50,000	90,000	150,000	285,000
HFO (m^3)	1700	2900	3800	7500
DO (m^3)	220	320	370	400

Description	750 TEU	1500 TEU	Panamax	Post-Pmax
DWT (MT)	9,000	20,000	45,000	75,000
HFO (m^3)	700	2000	5600	7600
DO (m^3)	130	200	330	430

Description	Handysize	Panamax	CapeSize
DWT (MT)	30,000	70,000	160,000
HFO (m^3)	1300	2200	4000
DO (m^3)	130	270	300

APPENDIX 3 – QUESTIONS FOR INTERVIEWS

1. What kind of experience do you have in arctic shipping?

2. What kind of ships do you have experience with?

3. What are your experiences with HFO use?

4. Does the quality of the HFO vary much?

5. Which type of HFO do you have most experience with?

6. Have you had experience switching between HFO and marine diesel, or the other way around?

a) Engine type?
b) Ship type, size, weight?
c) Which type of HFO (IFO 180, IFO 380, other?) was being used

7. In your experience, do the ships have automatic fuel changeover systems, or did the fuel changeover have to be done manually?

8. Have you experienced engine operational problems during a switching pro cess (engine stop, loss of power etc.)?

9. Have you experienced engine problems/failure during other operations, sailing, start in harbor or other?

10. Risks related to engine failure or stop/cause of failure

a) Fuel temperature (viscosity deviation)
b) Engine condition
c) Fuel problems (incompatibility, water)
d) Other (fuel system condition)

11. Have you experienced any challenges or problems with use of HFO in gen eral?

If yes:
a) What kind of challenges?
b) Can it be linked to the use of HFO?

12. Have you experienced any challenges with use of HFO in cold climate (Arc tic/Antarctica)?

If yes:
a) What kind of challenges?
b) Do you have consistent procedures to maintain acceptable viscosity?
c) Can it be linked to the use of HFO?

13. Risks related to fuel quality?

a) Remaining Cat-Fines in fuel oil (limits of Cat-Fines content, operation of separations, engine damages?)

b) Ignition and combustion quality? (Knocking combustion, Engine-Fuel adaption, engine damages).

14. Engine – fuel system condition and maintenance, experienced problems)

a) Worn fuel injection components – critical with low viscosity MGO

b) Reduced heating of fuel tanks and/or fuel pipes?

c) Other?