

Joint Industry Guidance

The supply and use of 0.50%-sulphur marine fuel



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Joint Industry Project sponsors



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Executive summary

Purpose of this document

In October 2016, the International Maritime Organization (IMO) confirmed a global limit for sulphur in fuel oil used on board ships of 0.50% m/m (mass by mass) to become effective on 1 January 2020. The implementation of this regulation will have far-reaching implications throughout the marine fuel supply chain, and will require detailed consideration by all parties associated with the production, distribution, storage, handling and use of these fuels. For this reason, a Joint Industry Project (JIP) has been established to raise awareness of these issues.

This document is one of the outcomes of the JIP. It provides guidance on the technical and safety implications of the new requirement for max. 0.50%-sulphur fuels, and is applicable to personnel involved in the marine fuels and shipping industries, from fuel blenders and suppliers through to end users. It provides a background to the MARPOL¹ Annex VI regulation as it affects the change to a new marine fuel regime, and addresses issues such as fuel compatibility, fuel stability, and fuel handling and storage, together with the operational factors that can affect safety. It makes frequent reference to IMO, CIMAC and ISO documents which should be consulted as necessary. This guidance document does not relieve any of the concerned parties (suppliers, purchasers and end users) of any of their responsibilities and obligations concerning the supply and use of marine fuel oil with a maximum of 0.50% m/m sulphur content. The document may be revised periodically as needed. In addition, the partners to the JIP are using this guidance as the basis for developing an e-learning course module for relevant stakeholders. The guidance is not intended to dictate the participants' commercial decision-making processes in any way, and is subject to the participants' individual corporate and commercial objectives.

How this document is structured

Introduction

The *Introduction* provides a background on air pollution from ships, summarizing the concerns raised about marine air pollution since the 1973 MARPOL Convention, and the eventual introduction of regulations to limit sulphur emissions from ships as specified in the revisions to MARPOL Annex VI.

The responsibilities of all stakeholders are presented, covering aspects ranging from quality control during fuel production, oversight of the supply chain, delivery considerations, sampling, on-board fuel management, treatment and fuel switching procedures.

¹ The International Convention for the Prevention of Pollution from Ships (MARPOL) is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes.

Section 1: Guidance on fuel characteristics and properties

This section begins with an overview of the need to observe good practice in on-board fuel management and underlines the importance of being able to understand the characteristics of the fuel as supplied.

Information is provided on the potential variability of max. 0.50%-sulphur fuels, and an introduction to marine diesel fuel requirements is presented in the context of the specifications contained in ISO 8217:2017, *Petroleum products—Fuels (class F)—Specifications of marine fuels*.²

A primer on key fuel properties is presented which includes information on cold flow properties, stability, viscosity, acid number, flashpoint, ignition quality and catalyst fines.

An analysis of fuel compatibility issues and the need to observe good practice when commingling fuels is provided, and a short summary of the test methods currently available for evaluating fuel quality brings Section 1 to a close.

Section 2: Guidance on the supply of max. 0.50%-sulphur fuels

Section 2 describes the need for fuel suppliers to have in place a robust Quality Management System (QMS, e.g. ISO 9001 or equivalent) that enables them to control the quality of the blend stocks used, avoid entry of extraneous materials, and ensure that appropriate blending methods are employed.

This section also outlines the need for suppliers and purchasers to provide enough information to the ship concerning the fuel as supplied, to enable ship operators to identify and manage potential safety and operational issues associated with certain fuel properties and characteristics.

The requirement of the ship's crew to maintain appropriate record-keeping on board in accordance with both MARPOL and Flag State requirements is also discussed.

Finally, this section emphasizes the need for fuel suppliers to ensure that the fuel supplied will not adversely impact the operation of the ship, and closes with a summary of the expectations of fuel suppliers, including their responsibility to supply fuels that meet the relevant requirements of Clause 5 of ISO 8217:2017 and Regulation 18.3 of MARPOL Annex VI.

² ISO 8217:2017, *Petroleum products—Fuels (class F)—Specifications of marine fuels*. International Organization for Standardization.
<https://www.iso.org/standard/64247.html>

Section 3: Guidance on the storage, handling and safe use of max. 0.50%-sulphur fuels

This section provides information on how ship operators can identify potential fuel-related safety and operational issues, together with details of the measures they can take to prevent and mitigate such issues.

A discussion of shipboard strategies for assessing compatibility of fuels is presented, followed by information on the challenges faced by the ship's crew in ensuring that the ship's equipment and systems are adequately prepared to accommodate the expected range of fuels.

Guidance is presented on switching between fuel parcels, with specific information relevant to ships using either diesel engines or boilers.

Finally, this section provides guidance on the on-board management of unacceptable fuels, off-specification fuels and non-compliant fuels (fuels exceeding the 0.50% sulphur limit).

Appendices

The document closes with three Appendices, which include: a list of definitions of frequently used terms (Appendix 1); details on the significance of off-specification test results (Appendix 2); and sources of guidance on ship implementation planning for the new max. 0.50%-sulphur fuels (Appendix 3).

Introduction

In October 2016, the International Maritime Organization (IMO) confirmed a global limit for sulphur in fuel oil used on board ships of 0.50% m/m (mass by mass) to become effective on 1 January 2020. Alternatively, ships may continue to use fuels with a higher sulphur content when using an equivalent method of compliance such as an exhaust gas cleaning system (EGCS). The implementation of this regulation by the IMO will have far-reaching implications throughout the marine fuel supply chain, from refining, through distribution, bunkering, handling and storage on board the ship, through to final use in boilers or in marine diesel engines for propulsion.

This document is designed to provide guidance for use across the marine fuels and shipping industries, from fuel blenders and suppliers to end users. It provides a background to the MARPOL Annex VI regulation as it affects the change to a new marine fuel regime; i.e. it presents the specific issues relating to the introduction and use of max. 0.50%-sulphur fuels, an overview of fuel quality principles, and the controls that should be put in place to ensure fuel quality and fitness for safe usage. It addresses issues such as fuel compatibility, fuel stability, and fuel handling and storage, and contains a comprehensive review of existing operational factors that can affect safety. It does not discuss compliance with Flag State, Port State or IMO rules or guidelines, or alternative means of compliance (e.g. EGCS, as mentioned above), and does not include a discussion of other fuels, e.g. liquefied natural gas, hydrogen, methanol, etc.

Background on air pollution from ships

The issue of controlling air pollution from ships—in particular, noxious gases from ships' exhausts—was discussed in the lead-up to the adoption of the 1973 MARPOL Convention. While it was decided not to include air pollution at the time, the issue of air pollution from ships was raised at the Second International Conference on the Protection of the North Sea in November of 1987. The major concern was acidification (acid rain) of eco-sensitive forests, contributed by ships in coastal waters.

The conference had issued a declaration in which the ministers of North Sea states agreed to initiate actions within appropriate bodies, such as the IMO, *'leading to improved quality standards of heavy fuels and to actively support this work aimed at reducing marine and atmospheric pollution.'* At the next session of the IMO's Marine Environmental Protection Committee (MEPC), held in March 1989, various countries submitted papers referring to fuel oil quality and atmospheric pollution, and it was agreed that the prevention of air pollution from ships should constitute part of the MEPC's long-term work programme, starting in March 1990.

MARPOL Annex VI, which was introduced by means of the 1997 Protocol,³ limits the main air pollutants contained in ships' exhaust gas, including sulphur oxides (SO_x) and nitrogen oxides (NO_x). MARPOL Annex VI also regulates the use of certain ozone depleting substances (ODS) and regulates shipboard incineration and the emissions of volatile organic compounds (VOCs) from tankers.

Following entry into force of MARPOL Annex VI on 19 May 2005, the MEPC, at its 53rd session (July 2005), agreed to revise MARPOL Annex VI with the aim of significantly strengthening the emission limits, considering technological improvements and implementation experience. The revised MARPOL Annex VI was adopted at the 58th session of the MEPC in October 2008.

The revised MARPOL Annex VI

MARPOL Annex VI is subject to ongoing change, and has seen progressive reductions in NO_x, SO_x and particulate matter (PM) globally, together with stepwise reductions in fuel sulphur levels in sulphur emission control areas (ECAs) as well as the introduction of NO_x Tier III ECAs in designated sea areas.

The 2008 amendments to MARPOL Annex VI included an agreement to reduce the sulphur limit outside ECAs, with an initial reduction from the existing limit of 4.50% to 3.50% max. from 1 January 2012, and then from 3.50% to 0.50%, effective 1 January 2020, subject to a fuel oil availability review to be completed no later than 2018.

The review of fuel oil availability, designed to inform the decision to be taken by the Parties to MARPOL Annex VI, was completed in 2016 and submitted for consideration at the 70th session of the MEPC (October 2016). The review concluded that enough compliant fuel oil would be available, and the IMO decided that the 0.50% sulphur limit in fuel oil would become effective on 1 January 2020. At the 73rd session of the MEPC in October 2018, a carriage ban was adopted requiring that the sulphur content of fuel oil used or carried for use on board a ship shall not exceed 0.50% m/m for ships without alternative methods of compliance (e.g. EGCS).

The corresponding fuel sulphur limits applicable in ECAs had previously been reduced from 1.00% to 0.10% on 1 January 2015, and the documented experiences with this changeover may be useful in preparing for the 1 January 2020 change to max. 0.50%-sulphur fuels.

³ Protocol of 1997 to amend the International Convention for the Prevention of Pollution from Ships of 2 November 1973, as modified by the Protocol of 17 February 1978. [http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/The-Protocol-of-1997-\(MARPOL-Annex-VI\).aspx](http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/The-Protocol-of-1997-(MARPOL-Annex-VI).aspx)

Responsibilities of fuel suppliers and fuel users

Responsibilities of fuel suppliers

Overview

Suppliers are expected to deliver a fuel which meets the parameters agreed between the supplier and the buyer. 'Supplier' in this context may not necessarily be the actual person delivering the fuel; the fuel supplier is the party responsible for the delivered quantity and quality either directly or through subcontractors. Likewise, 'meeting the needs of the ship' means that the fuel supplied should be stable in regular handling, homogeneous across the entire delivery and fit for purpose after appropriate on-board treatment (settling, centrifuging, heating and filtration).

The supplier is responsible for maintaining appropriate documentation to help identify product origins, including the manufacturing source and the various links in the supply chain, to enable traceability. Monitoring fuel quality at each step of the supply chain will also help to identify points of entry of any extraneous or harmful materials if these are discovered when the fuel is being used; where suppliers get components from other suppliers they should obtain assurance that appropriate supply chain quality control steps have been taken.⁴

It is important that the supplier delivers accurate information so that the ship operator can characterize the fuel supplied and take the appropriate initial steps in setting up procedures for the handling, treatment and use of that fuel. This information (e.g. special heating requirements) would be in addition to the required provision of the representative commercial samples, MARPOL delivered sample, material safety data sheets (MSDS) and bunker delivery notes (BDNs); the additional information would be in the format of a comprehensive certificate of quality (CoQ) or equivalent documentation.

Quality control during production of bunkers

Marine fuels, or bunkers, are hydrocarbon-based fuels for use on board a ship. They are primarily derived from petroleum sources and may also contain hydrocarbons from synthetic or renewable sources, as defined in ISO 8217:2017, *Petroleum products—Fuels (class F)—Specifications of marine fuels*. The bunker supplier should ensure control of individual blend component quality. This includes knowing the components' individual properties through accurate data, and the component origins supported by relevant documentation as agreed between the buyer and seller of the components.

Blend components should be of known suitability for bunker fuel production, with particular attention being given to ensure that the final product is stable.

The fuel should not contain harmful or damaging materials in concentrations that may cause damage as defined in Clause 5 of ISO 8217:2017 and Regulation 18.3 of MARPOL Annex VI. This does not preclude the use of additives intended to improve specific fuel characteristics such as cold flow or combustion properties. Any additive used should have a proven track record and should be thoroughly evaluated to ensure that it is fit for use in marine fuel applications.

⁴ Further details can be found in IMO (2018), *Guidance on best practice for fuel oil suppliers for assuring the quality of fuel oil delivered to ships*. MEPC.1/Circ.875.Add 1. <http://www.imo.org/en/OurWork/Environment/PollutionPrevention/Documents/MEPC.1-Circ.875-Add.1.pdf>

The supplier should ensure that the final blend, whether produced at a refinery or in a tank terminal, is tested at an accredited (e.g. ISO or equivalent certification) laboratory.

Transport, storage and transfer

Where actions in the supply chain are performed by other parties, these should be identified. The supplier should ensure control over, and maintain oversight of, the supply chain.

The quality of a bunker fuel or blend components may change compared to its origin during transportation, transfers and storage. The supplier should oversee the transportation of the fuel, blend components and additives to ensure that product contamination does not occur in tanker ships, shore tanks, pipelines, road tankers or barges prior to delivery. The supplier is expected to have in place a QMS (ISO 9001 or equivalent) to monitor, manage and assess the quality of the products they are supplying throughout the above processes.⁵

When arranging delivery, the supplier is expected to ensure that the product is supplied without cross-contamination from any other grade being supplied to the ship, or from any other material previously handled by the delivery facility. This is particularly important where delivery facilities are used to supply different grades of fuel and/or different sulphur specifications.

Delivery

If more than one grade of bunker fuel is to be supplied, the order in which the grades are supplied should be agreed between the supplier's representative and the ship's master or officer in charge of the bunker operation. To avoid contamination of product during delivery, it is recommended that the lighter/lowest sulphur grade is supplied first, followed by the heavier/higher sulphur grade.

Where necessary, segregated pipelines/hoses and bunker connections for supply of materially different types of product should be provided, e.g. for residual and distillate grades, and for high and low-sulphur bunkers, to prevent cross-contamination of products. The use of multiple bunker barges or other delivery facilities to discharge a single product in 'series' adds complexity to the delivery and will require additional management and oversight. In view of this, such operations should be avoided to the greatest extent possible.

Sampling

Representative samples should be drawn during the bunker delivery for retention by both the receiving ship and the supplier, in addition to the MARPOL delivered sample⁶ which is a statutory requirement. The sampling process should be witnessed by representatives for both the supplier and the receiving ship. The sample containers should then be sealed at least once (and countersealed if requested by the receiving ship) with tamper-evident seals that have a unique means of identification, and should be labelled, signed and countersigned by representatives of both parties.

⁵ IMO (2018). *Guidance on best practice for fuel oil suppliers for assuring the quality of fuel oil delivered to ships*. International Maritime Organization (IMO) circular 'MEPC.1/Circ.875/Add.1'. <http://www.imo.org/en/OurWork/Environment/PollutionPrevention/Documents/MEPC.1-Circ.875-Add.1.pdf>

⁶ IMO (2009). *2009 Guidelines for the sampling of fuel oil for determination of compliance with the revised Annex VI*. International Maritime Organization (IMO) Resolution 'MEPC.182[59]': [http://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Marine-Environment-Protection-Committee-\(MEPC\)/Documents/MEPC.182\[59\].pdf](http://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Marine-Environment-Protection-Committee-(MEPC)/Documents/MEPC.182[59].pdf)

Sampling in the supply chain

Sampling should take place at each point of product custody transfer throughout the supply chain. The supplier should retain the bunker transfer samples for at least 30 days. If a dispute over the fuel quality should arise, samples should be kept until the dispute has been resolved. The above should be documented in the supplier's QMS. This is a key part of a QMS; it enables transparency and traceability, and assists the supplier in identifying the origin of potential problems and taking steps to remedy and prevent further quality issues. It should be recognized that, in many ports, the contractual barge loading sample is often taken from the shore tank and not at a subsequent custody transfer point.

Responsibilities of fuel users

Overview

Reference should be made to the IMO guidelines for fuel users and fuel purchasers in MEPC.1/Circ.875.⁷ Fuel purchasers are expected to order fuel of a quality or grade suitable for the receiving ship, bearing in mind its intended trading area as well as the capabilities of the ship to receive, store, handle and use the fuel, including the ability to segregate different batches of fuel to safeguard against incompatibility issues. The fuel purchaser and the end user (the ship) should take note of the following:

- On-board fuel management is an essential element of preventing operational issues. Improper handling of fuel on board may lead to non-compliance with MARPOL requirements on fuel quality and safety, even if the fuel received was compliant. In this context, the following should be noted:
 - Once fuel is delivered on board, ships should have documented procedures for the safe handling and use of the fuel. These procedures should form part of the company's Safety Management System (SMS) which should be in place as a measure of good practice and/or as required by the International Safety Management (ISM) Code, as applicable, supported by equipment operating and maintenance manuals.
 - Each ship should have in place fuel switching procedures (where applicable). The ship's crew should be familiar with implementing these procedures.
- Marine fuel which fully meets statutory requirements and purchase specifications such as ISO 8217:2017, will nevertheless still require treatment before it meets most engine manufacturers' requirements.
- Where a ship is exempted from some of the provisions of MARPOL Annex VI under Regulation 3 of the Annex, or will comply with the requirements of the Convention using an equivalent means of compliance under Regulation 4 of the Annex, fuel oil purchasers should consider any conditions attached to the exemption or equivalent means which may affect fuel purchasing.

⁷ IMO (2018). *Guidance on best practice for fuel oil purchasers/users for assuring the quality of fuel oil used on board ships*. International Maritime Organization (IMO) circular 'MEPC.1/Circ.875'. http://www.imo.org/en/OurWork/Documents/MEPC_1-Circ-875_Guidance%20on%20Best%20Practice%20For%20Fuel%20oil%20PurchasersUsers.pdf

Guidance on fuel characteristics and properties

Overview

The application of supply quality assurance and good practice in on-board management and fuel care is needed to mitigate operational risks associated with the use of bunker fuels, provided it meets the statutory safety and quality requirements.

This can best be achieved by first carrying out an independent analysis of a representative sample of the fuel as delivered, to obtain an understanding of that fuel's characteristics. The machinery plant settings may then be adjusted accordingly, so that they are optimized for storage, treatment and combustion.

It is anticipated that there will be a wide variability in the formulation of max. 0.50%-sulphur fuels from light distillates through to heavier residual blends. In addition, high-sulphur fuel oil will also be available for ships fitted with equivalent compliance equipment.

The characteristics of max. 0.50%-sulphur fuels will be governed by the petroleum crude source from which they are derived, coupled with the availability of refinery processing and blending components. Fuel characteristics are expected to vary considerably, especially for the residual fuel grades, as it is anticipated that a range of residue streams and cutter stocks from refinery process units may be used as blending components. Fuel characteristics—especially density and viscosity—are also likely to vary with location and supplier. Due to variability in the chemical make-up of the fuels, it is anticipated that incompatibility will be more of an issue for max. 0.50%-sulphur fuels compared with present-day fuels.

Shipowners and operators should continue to procure fuels against ISO 8217:2017, as this Standard covers max. 0.50%-sulphur fuels in the same way that it covers present-day fuels. The same requirements currently defined in ISO 8217:2017 for fuels at the time and place of custody transfer (i.e. prior to conventional on-board treatment before use, including settling, centrifuging, filtration) will be applicable to max. 0.50%-sulphur fuels, including the General Requirements under Clause 5. This ISO Standard also states that supply facilities should have adequate quality assurance and management of change procedures in place to ensure that the resultant fuel is compliant with the requirements of the Standard. In this regard, nothing is changing in respect of the blending of 2020 fuels. Blend components will need to be permissible under the Scope and General Requirements clauses of ISO 8217:2017, including the requirement that a fuel shall be free from any material at a concentration that causes the fuel to be unacceptable for use. In all cases, the fuel must be compliant with the applicable provisions of the MARPOL and SOLAS Conventions.

The following text provides information on the potential variability of max. 0.50%-sulphur fuels with reference to key specific properties over and above the sulphur content. Compatibility is also addressed.

Potential variability of max. 0.50%-sulphur fuels

With the current maximum sulphur limit of 3.50%, all ship systems that could use residual grade products up to the viscosity norm of 380 cSt at 50°C (V50) and, in some cases, up to 700 cSt, will generally have been doing so. However, it is fully expected that fuel oils as supplied, meeting the 0.50% sulphur limit, will range from light distillates (DM—distillate marine) through to heavy residual fuel oil (RM—residual marine) with a range of widely differing fuel oil formulations in between.

Ships that usually operate outside an ECA will encounter greater variations in the composition and formulations of the fuel oils being supplied than they have previously been familiar with.

The increasing demand for very-low-sulphur fuel oil (VLSFO) is leading to an increase in the blending of lighter blend stocks to bring the sulphur content to 0.50%, and many of these are expected to be distillates. Ships will need to give more focus to a proactive management approach to addressing these variations and the accompanying uncertainties relating to handling and performance. This can be achieved by making sure that the ship's crew know the fuel characteristics as loaded, and that they are able to respond to the requirements for storage, handling and use of these fuels on board.

Fuel specifications, and their correct interpretation and application

ISO 8217:2017 specifies the requirements for fuels for use in marine diesel engines and boilers prior to conventional on-board treatment, and covers all sulphur content levels, including 0.10%, 0.50% and >0.50%-sulphur fuels.

This standard covers the technical boundaries defined by ship machinery installations and is used in most bunker purchase contracts. It is regularly reviewed (typically every three to five years) and updated to reflect the most recent market developments in fuels and machinery design. Previous editions are still being selected as the basis for contractual specifications for purchase agreements between fuel suppliers and the shipowner/operator; however, it is recommended that fuel buyers purchase and use the latest edition of the ISO 8217 Standard (ISO 8217:2017).

The latest edition of ISO 8217 was published in March 2017, following which the IMO requested the ISO to consider 0.50%-sulphur fuels in the framework of the Standard. Taking into account that a revision of ISO 8217:2017 was not possible in the available time frame, the development of a Publicly Available Specification (PAS), ISO PAS 23263, *Considerations for fuel suppliers and users regarding marine fuel quality in view of the implementation of maximum 0.50% S in 2020*, was initiated. The PAS will address the anticipated fuel characteristics and properties of the marine fuels that will be placed on the market to meet the 2020 sulphur requirements and will be used in conjunction with ISO 8217:2017.

Some distillate fuel formulations may have characteristics exceeding the maximum limits of DM/DF grades and, as such, can be considered within the context of ISO 8217:2017, Table 2. These fuel formulations typically have a higher viscosity and a more waxy nature, which can lead to inferior cold flow properties. When ordering a fuel, the ship operator needs to take into account the ship's specific technical capabilities and operational pattern, including ambient conditions, in order to select the most appropriate grade of fuel. This should take into account any specific limitation relating to one or more of the fuel characteristics listed below, such as maximum and minimum viscosity and cold flow properties.

Key fuel properties

Cold flow properties

The same principles that apply to present-day fuels with respect to cold flow properties will apply to max. 0.50%-sulphur marine fuels.

Fuel purchasers need an awareness of:

- any limitations that the ship may have in the area of cold flow management on board such as limited fuel heating capability;
- the intended voyage, and likely ambient temperatures to be encountered while that fuel is on board; and
- the cold flow properties of the fuel being purchased.

Significant operational problems can arise if supplied fuels are inappropriate for the ambient conditions, especially if the ship does not have adequate fuel heating capability; where relevant, cold flow properties should be specified in the purchase contract. Wax crystal formation starts at the cloud point (CP) temperature of the fuel and it is recommended that the supplier provides information on cloud point and cold filter plugging point (CFPP) temperatures so that the ship's crew can ensure that the bunker fuel temperature does not fall below these values.⁸ Reference should be made to the CIMAC document on the cold flow properties of marine fuel oils.⁹

The pour point is an important parameter used to ensure that fuels remain pumpable at low temperatures and to guide fuel storage temperatures. If fuels are held at temperatures close to, or below, the fuel pour point, the fuel may be difficult to pump, and separated wax may block filters and create deposits on heat exchangers. In severe cases, wax will build up in storage tank bottoms and on heating coils, which may restrict the coils from heating the fuels. In these extremes, it may not be possible to dissolve the wax simply by use of heating coils; manual cleaning of tanks or provision of additional temporary steam heating may be the only solutions.

⁸ Note: this only applies to product that is clear and bright in appearance.

⁹ CIMAC (2015). *CIMAC Guideline: Cold flow properties of marine fuel oils*. International Council on Combustion Engines. https://www.cimac.com/cms/upload/workinggroups/WG7/CIMAC_WG7_2015_01_Guideline_Cold_Flow_Properties_Marine_Fuel_Oils_final.pdf

When managing the anticipated variability of max. 0.50%-sulphur fuels, both distillate and residual, attention needs to be given to the cold flow properties to ensure that the fuel on board is maintained at a temperature high enough to avoid the problems described above; fuel should therefore be stored at a temperature which is **at least** 10°C above the pour point; the same recommendation applies to max. 0.50%-sulphur fuels. In order to reduce the risk of plugging and ensure a good circulation, fuel filters should be provided with a trace heating system having sufficient capacity to maintain the temperature inside the filter at a value which is higher than the CFPP of the fuels intended to be used.

Compared with residual fuels, distillate fuels have, in the past, generally not required heating. However, the increased use of distillate blending components with higher cloud points for the blending of low-sulphur fuels may necessitate some level of heating for fuel storage, transfer and injection. It is always recommended that distillate fuels are kept at a temperature which is at least 10°C above the pour point in storage, and at least 1°C above the CFPP temperature throughout the processing stages in filters and separators.

Stability

The stability of a fuel is defined in terms of its potential to change condition during storage and use. In terms of specification requirements, stability is normally assessed by measuring the total sediment, representing the sum of the insoluble organic and inorganic material separated from the bulk of a fuel sample by filtration through a standard filter under specified conditions.

Stability relates primarily to the potential for asphaltenes to precipitate and lead to the formation of sludge. The filtration tests do not differentiate between the inorganic sediment present in the fuel and the organic sludge components. While it is known that high levels of sludge can cause filtration and separator problems in the shipboard fuel systems, fuels meeting the sediment requirements specified in ISO 8217:2017 would be expected to be stable and not cause operational problems. (The sections on *Compatibility issues* on page 22 and *Avoiding Fuel Incompatibility issues (shipboard strategy and supplier liaison)* on page 36 provide a more detailed description of stability and its relation to compatibility.)

However, for max. 0.50%-sulphur blended fuels, the characteristics of the blending component feedstocks, method of production and type of cutter stocks used may be different from those in use today and, consequently, the current stability test methodologies for assessing fuel stability are being reassessed. It is anticipated that PAS 23263 and the CIMAC (International Council on Combustion Engines) guidelines will include further advice on methods for stability assessment and recommendations regarding their use. Suppliers will need to continue to supply fuels that are stable and homogeneous at the point of delivery, meeting the testing requirements as specified in ISO 8217:2017, and may take into account additional advice to be given in the forthcoming PAS 23263.

Additional concerns have been raised about the potential for tank stratification during storage due to the separation of heavier components in the fuel. Any separation may be more of an issue for max. 0.50%-sulphur blended fuels due to the wider variation in the density and viscosity anticipated between different fuel batches. The extent of any separation will be dependent on the fuel characteristics, storage conditions and storage time. While problems would not be expected to arise for a well-blended, homogeneous fuel oil during normal operation and handling, operational experience yet to be gained through the use of max. 0.50%-sulphur fuels will determine whether stratification is more of an issue with these fuels. In view of this, fuels should preferably be used on a 'first in/first out' basis. If stratification is suspected following testing of tank samples, recirculation of tank contents may be used (if possible) to homogenize the tank, while the ship's crew will need to be aware of the potential resulting variability of the fuel characteristics across the tank. In these circumstances, particular attention will need to be given to the viscosity and density of the fuel. Early indications of stratification may be picked up by the response of the viscosity controller to a change in fuel injection temperature. At this point, variability in the sulphur content of the fuel should also be considered.

With respect to the total sediment determined in the standard filtration specification testing, for present-day fuels greater emphasis is generally given to organic sludge existing in fuels rather than to any inorganic material that might be present. The assumption has been that the levels of inorganic sediment (e.g. extraneous sand, rust scale, catalyst fines, etc.) would be low, and that such material would be removed during normal handling operations (e.g. via centrifugal separators and filtration). While max. 0.50%-sulphur fuels may be produced using different blending component stocks from those used for present-day fuels, no increase in levels of inorganic sediment in the finished fuels is anticipated.

Viscosity

Due to the changes in the way that max. 0.50%-sulphur fuels will be manufactured, it is expected that there may be a wider variation in the viscosity (and density) of fuels received on board ships. (See also *Potential variability of max. 0.50%-sulphur fuels* on page 15). As is the case today, it is recognized that fuels bunkered at different geographical locations, or even those obtained from the same supplier at a given location, could have variable characteristics. The ship's crew will need to be more aware of the characteristics of the fuel being delivered, so that the correct procedural requirements can be identified and implemented with respect to storage, handling and operation.

The ability of the centrifugal separators to remove water and solids from the fuel is dependent on the fuel's viscosity; the lower the viscosity, the higher the separation efficiency. The recommended separation temperature for fuel oils with a viscosity above 180 cSt measured at 50°C is 98°C. For lighter grades, the equipment manufacturer's guidance should be followed, where lower temperatures are usually recommended. Fuel in storage tanks will also need to be heated to facilitate pumping; it is recommended that fuels are stored at a temperature which is at least 10°C above the pour point, and typically around 40°C (see also *Cold flow properties* on page 16).

Apart from the low-viscosity grades, fuels need to be heated prior to injection into engines (or burners) for combustion, to ensure that the viscosity is within the limits prescribed by the equipment manufacturer, typically in the range of 10 to 20 cSt, to obtain optimal spray patterns. Viscosity exceeding the manufacturer's specifications at the injectors may lead to poor combustion, deposit formation and energy loss; unburnt fuel may impinge on cylinder liner walls, and overpressurizing and overloading of the fuel injection pumps/piping and camshaft may occur. If the viscosity is too low, this may lead to inadequate dynamic lubrication of fuel injection equipment and poor distribution of the spray pattern in the combustion space.

Acid number

Acid number is an indication of the presence of acidic compounds in the fuel. Most often, these acidic compounds are weak acids, such as naphthenic acids, that are naturally occurring in the crude feedstocks and which may also originate, to a lesser extent, from fuel degradation during storage. The acid number is primarily linked to the crude source of the derived products. There is currently no evidence to suggest that the acidity of max. 0.50%-sulphur fuels will be significantly different from today's fuels, or that it will present increased operational risk.

Although it is rare, low levels of strong (inorganic) acids have been found in fuels, sometimes as a result of carryover from refinery processing.

Fuels with a high acid number have been known to cause corrosion of metal surfaces, especially in some types of fuel injection equipment; hence, limits for acid number are specified in ISO 8217:2017 for both distillate and residual fuels. ISO 8217:2017 also states that the fuel shall be free from inorganic acids; a fuel in which an inorganic acid species is present, even at very low levels, is likely to be corrosive. This aligns with MARPOL Annex VI, Regulation 18.3 which also states that the fuel shall be free from inorganic acids.

ISO 8217:2017 includes an informative annex on acidity which highlights that, while high acid numbers may be indicative of significant amounts of acid compounds and possibly other contaminants, some of which may be corrosive, fuels manufactured from naphthenic crudes can also have acid numbers exceeding the maximum specified but are still acceptable for use. However, acid numbers below the specified limits do not guarantee that the fuel is free from problems associated with the presence of acidic compounds.

Flashpoint

Apart from DMX grade fuel used for emergency purposes outside the machinery spaces, the minimum flashpoint defined in ISO 8217:2017 for distillate and residual grades is 60°C, reflecting the SOLAS (Safety of Life at Sea) requirement that all fuels used within machinery spaces on board the ship must have a minimum flashpoint of 60°C as determined by a closed-cup test method.

While there has been speculation that some max. 0.50%-sulphur fuels may exhibit flashpoints below 60°C because of changes in the way fuels will be manufactured to meet demand (e.g. due to the use of a lower flashpoint blend component), the existing regulatory minimum flashpoint requirement of 60°C will remain in place for 2020 and beyond. The fuel supplier remains responsible for ensuring that the fuels delivered meet the minimum flashpoint of 60°C to be compliant with ISO 8217:2017 and the SOLAS legislation.

The flashpoint of a fuel oil has no relation to its performance in an engine nor to its auto-ignition qualities. It does provide a useful check on suspected contaminants such as gasoline, since as little as 0.5% of gasoline present can markedly lower the flashpoint of the fuel. Ship classification societies also give instructions on the permissible temperatures at which fuels can be stored.

Flashpoint is considered to be an indicator of the fire hazard associated with the storage of marine residual fuels. However, it is not a definitive guide to safety, because even if fuels are stored at temperatures below the determined flashpoint, flammable vapours may still develop in the tank headspace, sometimes over a period of days before equilibrium is reached. The appropriate safety precautions, in line with legislation and local regulations relating to fuel storage and distribution, are necessary at all times.

Ignition quality

Ignition and combustion performance are important aspects of engine operation. Although both are dependent on the fuel characteristics, there is a wide range of other influencing factors including engine design, condition and settings, applied load, ambient conditions and fuel pre-treatment. Determining the ignition and combustion characteristics of a residual fuel oil in a simple and reliable manner has proven difficult.

The Calculated Carbon Aromaticity Index (CCAI) was developed as an indicator of the ignition performance of residual fuels in diesel engine applications and is calculated from the measured density and viscosity values. CCAI values typically range from 820 to 870; the higher the CCAI value, the worse the ignition quality. Limits for CCAI values were first included in ISO 8217:2010 as a guide to avoiding the use of fuels with uncharacteristic density-viscosity relationships (e.g. high density and low viscosity) which tend to exhibit poor ignition quality.

It is anticipated that max. 0.50%-sulphur marine fuels could exhibit a wider range of density and viscosity than currently found in the market, which means that there will be greater variation in observed CCAI values. The CCAI will continue to be of value in identifying and precluding the use of fuels with unusual viscosity/density relationships.

While the CCAI provides a readily available indication of the possible ignition performance of a fuel, the chemistry and characteristics of residual fuels have changed since its development in the 1980s; this means that some fuels available today, which have similar densities and viscosities and similar CCAI values, can have significantly different ignition characteristics. Some fuels with an acceptable CCAI value may exhibit poor ignition characteristics in some engines. Also, some fuels may exhibit poor ignition properties but acceptable combustion properties, and vice versa.

To address both the ignition and combustion characteristics of a residual fuel, a standard test method, IP 541, was developed in which fuel is sprayed into a pressurized constant volume combustion chamber at elevated temperature and pressure. The technique is useful for fuel characterization, especially when in-service combustion problems have been experienced.

Some engine manufacturers specify CCAI and IP 541 limits for their engines, depending on engine type and application; details may be found in the CIMAC report, *Fuel Quality Guide—Ignition and Combustion*.¹⁰

Catalyst fines

Catalyst fines originate from fuel blending components derived from the refinery fluid catalyst cracking unit. There has been speculation that such components will find increased use in the blending of max. 0.50%-sulphur marine fuels; however, the requirement to meet the existing ISO 8217:2017 aluminium and silicon (Al+Si) content limit of 60 mg/kg maximum will remain in force and suppliers will need to continue to supply compliant fuels. While there is currently no evidence to indicate that max. 0.50%-sulphur marketed fuels will see significantly increased levels of Al+Si content, any changing trends will become apparent as experience is gained in the use of these fuels.

Excessive levels of catalyst fines can cause accelerated abrasive wear of fuel pumps, injectors, piston rings and cylinder liners. It is essential that residual fuel is pre-treated through a combination of settling and centrifuging prior to combustion to reduce the level of catalyst fines to a tolerable level, thereby avoiding potentially excessive damage. In this respect, information on the key fuel properties (see pages 16–21) will assist the receiving ship in the handling and treatment of the fuel on board and should be available from the supplier as appropriate. For max. 0.50%-sulphur fuels exhibiting lower density and/or viscosity, separation of extraneous materials from fuels during settling and centrifuging will be correspondingly enhanced.

If it is suspected that an engine is operating on fuel with an elevated level of catalyst fines, it is recommended that operation of the centrifugal separators is fully optimized and monitored closely. Samples taken before and after the fuel is passed through the separators should be tested to determine the removal efficiency of the separators. Monitoring the frequency of backflushing and pressure drop through the automatic self-cleaning filter (main filter) can indicate a change of fuel quality or cleaning efficiency. It is also advisable to carry out more frequent inspections of susceptible engine parts to provide an early warning of any accelerated wear. Advice from the manufacturer of the on-board separator machinery should be sought for remedial measures to be adopted, such as separation on low throughput, parallel passes through separator arrangements, etc.

¹⁰ CIMAC (2011). *Fuel Quality Guide—Ignition and Combustion*. The International Council on Combustion Engines.
<https://www.cimac.com/publications/wg-publications/cimac-wg07-fuel-quality-guide-ignition-and-combustion.html>

Compatibility issues

To understand the increased risk of incompatibility arising from the introduction of max. 0.50%-sulphur fuels, an explanation of the principles of asphaltene precipitation leading to sludge formation is provided below.

A residual fuel can be looked upon as a colloidal dispersion of asphaltenes uniformly distributed throughout an oily medium, often referred to as a 'continuous phase'. For a stable residual fuel oil, a state of equilibrium exists between the asphaltenes and the continuous phase, and the asphaltenes will remain in stable dispersion. However, changes to the chemical characteristics of the asphaltenes (for example by exposure to high temperatures in some refining processes) or to the continuous oil phase (for example by blending two different fuel oils together or blending a cutter stock into the residual fuel) can upset the equilibrium. When this happens, the asphaltenes will no longer be held in stable dispersion, but will instead begin to agglomerate (or flocculate). The larger agglomerated particles may start to drop out of the fuel, producing what is referred to as sludge.

Depending on the level of precipitation, the presence of sludge in bunker fuel has the potential to cause significant operational impacts through accumulation in tanks and fuel lines, choking of separators and filters, and sticking of fuel injection pumps. Instances of mild levels of sludge can generally be dealt with successfully by the ship's crew, albeit requiring increased cleaning and maintenance of separators and filters. High levels of sludge can cause severe fouling which, if not dealt with, can result in the potential interruption of the fuel supply to the engine (fuel starvation) and, ultimately, loss of power and propulsion. Additionally, combustion can be compromised through excessive fouling of the cylinders, causing piston rings to stick and differential thermal loadings on the cylinders, which can potentially result in engine failure.

A residual fuel is defined as stable if asphaltenic material is not precipitated during normal storage and use. The 'Total Sediment Potential' (TSP) test method (ISO 10307-2 Procedure A, thermal ageing) simulates normal storage by measuring the sediment which includes asphaltenic sludge, after heating it to 100°C for 24 hours. If the TSP does not exceed the specification limit of 0.10% m/m, it is normally assumed to be stable. However, if significant precipitation still occurs, the fuel is said to be unstable.

The term 'compatibility' is often confused with stability, but although the chemical and physical processes at work are the same, these terms have different meanings. Compatibility cannot be described as a characteristic of a single fuel, rather it is an indication of the suitability of commingling one fuel with another. If two fuels are commingled together and the resulting blend remains stable (i.e. does not precipitate asphaltenic sludge), the fuels would be termed compatible. On the other hand, if the resulting blend is unstable, then the component fuels are said to be incompatible, even though each component is individually stable. Incompatibility generally arises as a consequence of lack of stability reserve and changes to the solvency of the continuous phase for the asphaltenes.

Good practice when commingling fuels

The industry good practice is, in the first instance, to **avoid commingling fuels** from different sources in bunker tanks, because arbitrary commingling can lead to incompatibility and loss of stability of the resultant blend. For example, when a residual fuel oil is commingled with a distillate with a predominance of paraffinic hydrocarbons, the solvency reserve can be depleted and asphaltenes can flocculate and precipitate as sludge. In such a case, there would be an increased risk of problems arising during fuel switching, such as when entering or leaving an ECA, when fuels become commingled in settling and service tanks. Precautionary measures to minimize or preferably eliminate commingling in the tanks will help to reduce this risk. It is anticipated that issues of incompatibility could become more prevalent with max. 0.50%-sulphur content fuels. Fuels meeting the new limit may be blended from a wider range of blending components than currently utilized today (see also *Responsibilities of fuel suppliers* on page 11, and the *Overview* in this section on page 14). Depending on the manufacturing route and blending component availability, the blended fuels may be predominantly aromatic or paraffinic in nature, or somewhere in between. While these fuels will be stable in their own right, the variation in paraffinic/aromaticity may lead to an increased risk of incompatibility when commingled.

It is recognized that fuels bunkered at different geographical locations (even fuels obtained from the same supplier) may not be compatible. It is therefore important that commingling of bunker fuels from different batches is avoided. It should also be noted that commingling may not result in an homogeneous product; ships should continue to segregate bunker stems on board and minimize their commingling throughout the fuel system, in line with standard operating procedures. This includes potential commingling in bunker fuel tanks and settling/service tanks. In addition to potential incompatibility between residual fuels, there is also a higher risk when commingling distillate and residual fuels, as these may also be incompatible.

In practice, complete segregation will not be possible and even in 'empty' tanks there will be a degree of commingling due to the presence of existing tank products, e.g. in the heel of the tank or in the transfer system pipework. Carrying out a compatibility test between the existing and proposed bunker fuel delivery is the only way to provide a realistic indication as to the potential issues that might result.

The most widely used **on-board** test method for compatibility assessment is ASTM D4740, the *Standard Test Method for Cleanliness and Compatibility of Residual Fuels by Spot Test*. This one-hour test can be performed by the ship's personnel using an on-board test kit (as well as in a laboratory); however, its efficacy and accuracy depends heavily on the proficiency and experience of the ships' crew in the interpretation of the spots, and it will only be of benefit to the ship if its personnel can become proficient in carrying out this test.

The test method was initially developed to assess the degree to which asphaltenes were already precipitated in the as-received sample (the so-called 'cleanliness procedure'). For compatibility assessment, samples of the two fuels which may be commingled are mixed in the expected ratio in which they will be used. The blend is then tested according to the cleanliness procedure.

Users of this test method should be alerted to the fact that the test may be less predictive/accurate for 0.10% sulphur fuels and the max. 0.50% sulphur fuels made available leading up to 2020 and beyond. This is anticipated to be due to the variable characteristics of the fuel blending components that will be used in their manufacture, particularly those with a high wax content. Personnel involved in handling bunker fuels, whether shoreside or shipside, should ensure that any recommendations or new methodologies are adopted for use, to minimize the risks associated with both stability and compatibility. Further information on compatibility testing is provided in Section 3 under *Avoiding fuel incompatibility issues (shipboard strategy and supplier liaison)*.

Test methods available for evaluating fuel quality

Test methods available for evaluating fuel quality include the methods listed in Tables 1 and 2 of ISO 8217:2017. In addition to the ASTM D4740 test method mentioned above, further test methods to evaluate the compatibility between two fuels are available.

Currently, a very limited number of tests—including tests for specific gravity/density and viscosity, and the compatibility or spot test (ASTM D 4740)—can be carried out on board the ship. Additionally, the ISO 10307-2 Procedure B (chemical ageing) Total Sediment Accelerated (TSA) test and the more relevant 10307-2 Procedure A (thermal ageing) Total Sediment Potential (TSP) test are available at onshore laboratories, where TSP is the single referee method defined in ISO 8217:2017.

Recent studies to evaluate the stability of, and compatibility between, the max 0.50%-sulphur marine fuels that will be available on the market showed that some fuels might exhibit a TSA value well within the 0.10% m/m limit, but when using the referee method may exhibit a TSP value exceeding the 0.10% m/m limit. To ensure that the total sediment (aged) limit as specified in Table 2 of ISO 8217:2017 has been met, it is recommended that the referee test method (TSP) is used. Unlike the ASTM D4740 spot test, which takes approximately 1 hour, the TSP test takes 24 hours; however, as mentioned above, the spot test depends heavily on the proficiency and experience of the ships' crew in the interpretation of the spots.

Guidance on the supply of max. 0.50%-sulphur fuels

A fuel supplier needs to have in place a robust and applied QMS which addresses all of the factors that affect the quality or characteristics/properties of the fuel which is to be supplied, and the ability to meet the ordered specification, by:

- controlling the quality of the individual blend stocks used to produce the fuel;
- avoiding the entry of extraneous, potentially harmful, materials within the supplier's (or upstream) storage, handling and delivery systems; and
- ensuring that the correct blending procedures are applied so that a homogeneous fuel is delivered.

Blend stocks

The actual physical supplier of a consignment of fuel may be a refinery operator supplying fuel based on blend stocks received directly from its own refineries. In other instances, the blend stocks used will have been traded, potentially a number of times, by brokers between the various sources and the final supplier; this may have involved the splitting and mixing of different consignments along the way. Irrespective of the particular supply chain, it will become increasingly important for these operations to be documented so that both the final supplier and the shipowner/operator understand the characteristics of the fuel.

Extraneous materials

The effective application of a robust QMS by fuel oil suppliers will minimize the risk of undesirable material entering the fuel or its constituent components. Such material could be extraneous to the fuel product, e.g. water (covered by ISO 8217:2017; includes fresh/brackish/saline—together with the risk that it may encourage proliferation of bacteria in the interphase between fuel and water), dust, maintenance materials or corrosion debris. Alternatively, such undesirable material could be other fuel/hydrocarbon products, e.g. line residues, washings, or materials remaining in shore tanks or barges (including 'unpumpables'). In some instances, this extraneous material has been found to contain waste chemicals and other such material for which marine fuels are occasionally seen by some as a convenient disposal route. The addition of used lubricating oil (ULO) as a fuel blend component from both shipboard and land-based sources can also provide a route for waste materials to enter the fuel pool, and can add undesirable contaminants from anti-wear additives containing zinc, calcium and phosphorous.

The blend process

Regardless of where the blending takes place, the supplier's intent should be to make the best use of the available component products to maintain the quality characteristics. However, since a residual fuel needs to be blended to achieve the required viscosity and density, with attention also being paid to achieving the required sulphur content limit (all other residual fuel characteristics will usually be what is normally expected, being that they are mostly interrelated), there will inevitably be some compromises. For example, such blending may, on occasion, result in the delivery of a fuel which has a much lower viscosity than the specification ordered. This situation is likely to be exacerbated for many types of fuel with the introduction of the post-2020 sulphur limit of 0.50% m/m. When sulphur content is used as a defined 'not to be exceeded' blend target, other parameters such as viscosity and density may vary extensively compared to that in an unconstrained sulphur regime.

For blending to be undertaken correctly in the first instance there needs to be accurate data (e.g. on viscosity and density, together with sulphur if that is a factor) in respect of the blend components to be used. Secondly, the blend proportions determined from those data need to be calculated correctly and then established, after which they should be uniformly maintained.

Blending should, in principle, only take place on shore in order to ensure that the end product is homogeneous. Variable in-line blending during delivery, where ratios of components are continuously adjusted to meet blend targets, can result in the delivery of a non-homogeneous product—an issue that may not be detected from the continuous drip samples taken over the whole of the bunkering period. This may have potentially serious consequences for the end user, particularly where the fuel is loaded in series into a number of different tanks, and should therefore be avoided. As bunker barges and similar vessels will be used within bunker supply chains, any blending that is carried out on board should be in compliance with SOLAS Chapter VI, Regulation 5.2.

It is the duty of the fuel supplier in producing the blended fuel to be delivered, or indeed of any other party upstream from that point, to ensure that all component blend stocks, including cutter stocks, that are to be mixed are mutually compatible and will not result in asphaltene precipitation. Furthermore, it is imperative that the various components are sufficiently well mixed to ensure that the fuel will not tend to settle out to its original components over time—a process known as stratification; again, this is an issue that would not normally be detected from continuous drip sample testing; see also *Stability* on page 17.

To ensure that the product conforms to relevant specifications and statutory limits, the final blend should always be tested against the relevant standards, and the test results documented. Once a bunker blend has been produced and tested, appropriate storage and product handling, both in shore tanks and on-board cargo and bunker supply tankers, should be adopted to maintain product integrity.

Information that should be provided by fuel suppliers to allow ship operators to identify and manage potential safety and operational issues associated with certain fuel properties and characteristics

The fuel supplier should provide the receiving ship with enough information on the fuel to be supplied, so that the ship's crew are able to safely and effectively deal with that fuel in terms of storage, handling, treatment and use of the fuel on board. The supplier also has an obligation to communicate clearly to the receiving ship the quantities and grades that they have arranged to supply; this information from the supplier should be provided in enough time to enable the ship's crew to prepare for the bunker delivery and the appropriate storage of the fuel on board—ideally 2–3 days prior to the ship's bunkering schedule.

Typically, the specific information to be supplied should, at a minimum, include:

- confirmation of the ordering specification;
- viscosity;
- density;
- cold flow properties such as pour point and CFPP/CP as applicable to the grade of fuel;
- any other information that the supplier considers operationally useful for the ship to know; and
- a full CoQ relating to the current fuel.

Equally, the ship's crew should understand the information received and be able to prepare the system for the receipt of the bunkers.

The supplier (or the delivery contractor) should be made aware of any special circumstances that may affect the delivery of fuel to the ship; this would normally be done by the ship's agent in the delivery port.

The supplier and the ship's crew should follow the appropriate guidance on the conduct of the delivery. This is especially important with regard to the completion of documentation such as the BDN, as well as the management of the samples and the mandatory MARPOL delivered sample. The receiving ship should immediately inform all responsible parties about any samples or documentation (e.g. MSDS, fully compliant BDN, IMO sampling guidelines, etc.) that are either not provided or which they believe do not meet the relevant provisions contained in the SOLAS or MARPOL Conventions. Records of such communications should be maintained on the ship for future reference/inspections, alongside the actual MSDS, BDNs and CoQ or equivalent documentation.

Appropriate record-keeping should be maintained on board the ship in line with MARPOL and Flag State requirements, as per MARPOL Annex I, Regulation 17. The receiving ship should have procedures established for bunkering, fuel handling and storage of fuel, including spill, pollution and emergency response. Shipboard emergency plans addressing different categories of emergencies are required under the provisions of both the SOLAS and MARPOL Conventions, as well as the ISM Code and supporting guidance.

Detailed guidance for bunkering procedures, including a sample bunkering checklist, may be found in various available guidance documents, and is also covered by the latest revisions of the international standard ISO 13739, *Petroleum Products—Procedures for transfer of Bunkers to Vessels*, and national standards such as the Singapore *Code of practice for bunkering* [SS 600].

Under MARPOL Annex VI, it is a statutory requirement that a BDN includes at least the stipulated information and declaration, and this must be provided by the supplier to the ship. As well as meeting the minimum MARPOL requirements relating to the supply of information on the fuel's density and sulphur content, additional information that should be provided in writing includes, but is not limited to, data (i.e. actual values, not a range) on:

- pour point (if higher than -6°C : actual value);
- viscosity; and
- water.

For distillate fuels the information should also include data on:

- cloud point (only applicable to clear and bright distillates); and
- cold filter plugging point (CFPP).

Additionally, it should be confirmed that the flashpoint of the fuel is in compliance with the SOLAS limit, i.e. a minimum of 60°C .

Additional information may be provided on the chemical characteristics of the fuel to assist the ship's crew in assessing the associated compatibility risks of any commingling with other fuels on board (see *Avoiding fuel incompatibility issues (shipboard strategy and supplier liaison)* on page 36).

An MSDS should be provided as per SOLAS requirements.

With regard to the sulphur content, the supplier must state the actual sulphur content in accordance with the MARPOL Annex VI BDN requirement rather than advising that the sulphur constitutes $<X\%$. A specific value will enable the ship's crew to manage the fuel grade switching when entering an ECA and to monitor the effectiveness of any abatement technology being used on board.

Measures that fuel suppliers should take to ensure that the fuel supplied to the ship will not adversely impact the safe operation of the ship

Suppliers should ensure that their supply chain quality management procedures allow them to demonstrate that the quality of the product being supplied was assessed by accredited laboratories when received, and that the product can be, and has been, tracked throughout any blending or processing while under their control. Particular attention should be paid to preventing contamination by other products. Suppliers need to be aware that the source of such contamination is frequently traced to storage tanks, pipeline contents or transportation (road tankers or barges).

Expectations of fuel suppliers, including their responsibility to supply fuels that meet the relevant requirements of MARPOL Annex VI

Suppliers are expected to supply fuel which is compliant with the requirements of SOLAS Chapter II-2 and Regulations 14 and 18.3 of MARPOL Annex VI. Verification of compliance with these requirements falls within the jurisdiction of the Port State in which the suppliers are registered. Suppliers are also expected to supply fuel which meets the appropriate grade as specified in ISO 8217:2017, and the specified maximum sulphur content if that was part of their contractual agreement with the buyer. If an alternative standard or specification was agreed between seller and buyer, the fuel supplied is to meet that requirement of the contract.

As advised in ISO 8217:2017, it is not practical to require detailed chemical analysis for each delivery of fuel beyond the requirements listed in Table 1 (distillate marine) or Table 2 (residual marine) in the Standard. Instead, as detailed above, the supplier should have in place adequate supply chain quality management procedures to ensure that fuel is compliant with the requirements of Clause 5 of ISO 8217:2017 and Regulation 18.3 of MARPOL Annex VI. Where a CoQ is requested or provided, the parameters listed in either Table 1 or Table 2, as applicable, should be included in the CoQ. If, after delivery of the fuel, the supplier becomes aware of an issue with the fuel, they should advise the buyer/receiving ship immediately to enable appropriate action to be taken.

Guidance on the storage, handling and safe use of max. 0.50%-sulphur fuels

How ship operators can identify potential fuel-related safety and operational issues, and the measures they can take to prevent and mitigate such issues

In general, fuels should be handled as currently, with particular attention to the avoidance of commingling: the preferred default situation for bunkers coming on board a ship is complete segregation. However, it is accepted that this may not always be possible or practical. This section provides guidance on identifying and addressing the issues that may arise from the planning stage through to delivery of the fuel on board the ship.

Fuel as supplied: identification of quality

Having identified the ship's fuel quantity and quality requirements, the shipowner/operator should, before ordering a fuel, determine whether the ship will have sufficient empty tankage to receive the full quantity expected. If the ship does not have sufficient empty tankage available, extra care will need to be taken by way of applying a predesigned commingling plan to address the risks of non-compatibility and provide a clear path of instruction for all possible scenarios that could confront the ship; this may involve the redistribution of fuels into several tanks to minimize the risks. Reference should also be made to the subsection on *Responsibilities of fuel users* in Section 1 (page 13). At this point, if possible, the ship should establish the characteristics of the proposed bunkers compared to that already on board. This assessment is difficult and will be based primarily on an assessment of differences in fuel characteristics such as density, viscosity, CCAI value and micro carbon residue (MCR) value, where wider variances would indicate a lower likelihood of the two fuels being compatible.

Pre-delivery documentation

From the receiver's/user's perspective the first indication of quality will normally be the pre-delivery documentation provided by the supplier before the transfer of fuel begins. At this stage, it should be established that the advised details of the product to be supplied are in accordance with the specification that was ordered. If the ship's staff are in any doubt, they should inform their management and should not load fuel until they are satisfied that adequate documentation has been received.

During delivery

Over the course of the delivery, the receiver/user should maintain vigilance over the quality aspects of the fuel being supplied. For example, prudent questions could include the following:

- Are all the required samples being drawn in a manner that indicates that they will be representative of the fuel supplied?
- What other activities are occurring? In the case of a bunker barge alongside the receiving ship, is the operation being conducted without problems, and is the barge alongside the sole source, or are other barges pumping through that barge to the ship or simultaneously supplying other products to the ship?
- Does the fuel appear to be supplied as a homogeneous product; has air-blowing been overused; is there an unusual odour; and are other abnormal characteristics or observed practices apparent?

All observations should be documented by the ship's crew, and a representative sample should be taken in accordance with IMO guidelines.¹¹

Completion of delivery

On completion of the delivery, the following questions should be addressed:

- Do the details on the BDN relating to quality correspond to the pre-delivery data and the ship's requirements?
- Have the commercial samples and the MARPOL delivered sample been correctly prepared, documented and securely sealed as required?
- Have arrangements been made to retain the samples for a minimum of 12 months in an appropriate and safely ventilated storage location?

It is the shipowner's choice as to whether they go further and arrange for tests to be carried out on a sample of the fuel as supplied, noting that the MARPOL delivered sample is not for the ship's use in such testing. For many, this now represents a standard part of the quality chain, with the fuel not being brought into use until the relevant test report is available.

¹¹ IMO (2009). *2009 Guidelines for the sampling of fuel oil for determination of compliance with the revised Annex VI*. International Maritime Organization (IMO) Resolution 'MEPC.182(59)'. [http://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Marine-Environment-Protection-Committee-\(MEPC\)/Documents/MEPC.182\(59\).pdf](http://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Marine-Environment-Protection-Committee-(MEPC)/Documents/MEPC.182(59).pdf)

Testing the fuel

A number of options have been made available over the years for on-board testing using portable test units to assess aspects such as compatibility, viscosity, density, water and catalyst fines. However, such units are only able to provide indications. While such indications may, at times, be extremely important and highly useful, they do not provide a basis on which to challenge whether the specification limits have been met, or to take substantial decisions as to whether a fuel should be considered usable/unusable, unless the results are confirmed by an analysis at an accredited laboratory.

For test results to carry weight, they should be undertaken at a laboratory which is accredited to ISO 17025 or an equivalent national standard for the tests being carried out.

The various fuel testing services available today all provide standard test packages which are designed principally to assess the characteristics of marine fuel oil as defined in the ISO 8217:2017 specification. Each characteristic is defined by one or more test procedures, the results of which can then be used to evaluate the fuel as supplied. A summary of key fuel quality characteristics are reviewed in Appendix 2 of this document.

Assessing fuel quality

Given the basic framework of ISO 8217:2017, an assessment of the quality of a fuel as supplied may be divided into three subsets, namely statutory requirements, defined limits and general requirements:

Statutory requirements: The SOLAS and MARPOL Conventions include mandatory specific requirements for parameters such as flashpoint and sulphur content, as well as mandatory general provisions for fuel oil quality and safety.

Defined limits: These would be seen as the numeric limits as given in Table 1 or Table 2 of ISO 8217:2017. These limits are in respect of certain physical properties, composition or performance indicators.

General requirements are discussed on the following page.

General requirements

Irrespective of meeting the statutory and defined limits, the fuel supplied must be acceptable for use subject to fuel treatment on board, as given by Clause 5 of ISO 8217:2017 and Regulation 18.3 of MARPOL Annex VI.

Additionally, ISO 8217:2017 Clause 5.2 requires that:

'The fuel shall be free from any material at a concentration that causes the fuel to be unacceptable for use in accordance with Clause 1 (i.e. material not at a concentration that is harmful to personnel, jeopardizes the safety of the ship, or adversely affects the performance of the machinery)'

and Regulation 18.3.1 of MARPOL Annex VI requires that:

'The fuel oil shall not include any added substance or chemical waste which either:

- (1) jeopardizes the safety of ships or adversely affects the performance of the machinery; or*
- (2) is harmful to personnel; or*
- (3) contributes overall to additional air pollution.'*

While ISO 8217:2017 specifies certain fuel quality requirements—such as being free of both inorganic acids and used lubricating oil—other aspects exist which may render a fuel *'unacceptable for use in marine applications'* (e.g. the presence of certain petrochemicals and other such contaminants) which are not readily identifiable other than by specialist, specific, time-consuming and costly tests methods. Given the multitude of possible test methods, some of which are proprietary and non-standardized, such testing will normally only be undertaken after a problem is encountered—the problem being the first indication that additional testing should be undertaken and what that testing should be looking for.

Even then, having identified an 'unusual' component, its quantification will need to be fully understood, both in absolute terms and relative to other fuels in general. Furthermore, it is often not possible to link such a finding to problems that may be encountered on board the ship; indeed, different engines/on-board systems may seemingly have used the 'same' fuel but with widely differing outcomes.

Questions to ask when considering whether the quality of fuel supplied is as requested

The question of the real-world quality of the fuel as supplied to the ship may be considered as a two-part question:

Criteria 1

- Does the fuel meet the ordered specification? In the case of an order based on the fuel quality requirements specified in ISO 8217:2017, have the relevant statutory and defined limits been complied with (recognizing that, in terms of the 'acceptable for use' aspect, certain aspects of this point will normally only be capable of assessment only after the fuel has been brought into use)?

Criteria 2

- Where the fuel has not met one or more of the statutory or defined limits, does this render the fuel unusable or, with a certain amount of effort towards addressing the particular points identified, could it be used without undue risk?

Collection of evidence relating to poor quality fuel performance

In a case of poor fuel performance, where the only factor that has changed is the fuel supplied to an engine that has a previous (and subsequent) history of satisfactory running, and it can be shown that all the usual care has been taken in relation to storage, handling and treatment, the evidence may indicate that the problem is due to the quality of the fuel as supplied. The process of gathering such evidence is critical to establishing that a fault is due to the quality of the fuel as supplied, rather than due to a failure of fuel management on board the ship.

This distinction is important since there is, in practical terms for the ship, a time dynamic—it is the **responsibility of the supplier, not the receiver**, to ensure that the product delivered meets the requirements of the ordered specified grade and fuel characteristics, as agreed with the purchaser.

In cases where, for the receiver's own information, fuel testing is to be done, a worthwhile representative sample can only be drawn over the whole of the supply period, by which time the fuel will already be in the ship's tank(s).

The fuel will always be on board before it can be assessed, typically by dispatch of a sample to one of the fuel testing services. Because of the time required to complete the testing process, a ship will normally have sailed from the port of supply before the quality of the fuel received is established, at least in terms of the statutory and defined quality limits.

Even where that is not the case, for example where a potential problem is identified from the information given on the BDN, such that the delivered fuel is unsuitable for use, debunkering at that stage may not be an acceptable option, being that it is a lengthy and difficult process.

On-board management of unacceptable fuels or fuels exceeding the sulphur limit

Once on board, no fuel is readily offloaded—even where there is supplier agreement. Any quality dispute process will, given the financial and other implications, take time to resolve and will not necessarily conclude with the fuel being offloaded. In the meantime, the ship's fuel storage capacity is reduced, possibly substantially, by a fuel which is not at that time available for use.

In all but the most extreme cases, offloading a fuel which fails to meet the required specifications is not an optimum outcome for any of the parties involved. Furthermore, the ship will invariably have departed from the port of supply before any agreement to offload is concluded, raising questions not only of the physical arrangements for offloading the fuel, but also of who is to receive that fuel bearing in mind its product status as being a fuel of 'unacceptable' quality.

Regulation 18.2 of MARPOL VI includes provisions for cases where a ship is unable to load compliant fuel, e.g. due to lack of availability. In such cases, the ship should notify its Administration and the competent authority of the port of destination in accordance with the requirements of Regulation 18.2 (i.e. including submission of a fuel oil non-availability report—FONAR). In such cases, the parties to the Convention should take into account all relevant circumstances, together with the evidence presented, to determine whether or not appropriate action, e.g. de-bunkering, should be taken. This in itself may present significant problems as the physical arrangement of the ship may not easily facilitate de-bunkering. If the fuel needs to be discharged, it may be necessary to clean the bunker tank to ensure that subsequent fuel is not contaminated by the previous stem of fuel.

Fuel quality characteristics and the significance of off-specification test results

Appendix 2 on pages 52–57 provides a brief on the potential significance of the various characteristics specified in Tables 1 and 2 of ISO 8217:2017, together with other characteristics which fall under the general requirements and Clause 5, when off-specification. It should be noted that this is not an exhaustive list, rather it provides an indication of some of the possible outcomes of an off-specification product being supplied to a ship. In Tables 1 and 2 of ISO 8217:2017, RM fuels categorize fuels that require heating for injection, and DM fuels categorize those that do not require heating for injection. It should not be overlooked that fuel blends which are more paraffinic in nature may require heating to address any requirement to maintain the waxes in liquid form for effective management of the fuels' cold flow properties.

Avoiding fuel incompatibility issues (shipboard strategy and supplier liaison)¹²

Compatibility is a known issue with residual fuels, but improvements in understanding and testing practices have resulted in a reduction in the number of incompatibility cases over the years. While it should be noted that incompatibility is not an issue if commingling pure distillates (i.e. fuels with no residual fuel oil component), it is important to remember that:

- a distillate fuel could be incompatible with a residual fuel; and
- just because two residual or blended fuels may themselves be 'on specification' does not necessarily mean that they are compatible.

In these guidelines, repeated emphasis has been placed on the desirability of segregating bunkers rather than commingling. The basic rule is to aim for complete segregation of a new bunker stem: commingling of different fuels (often referred to as 'loading on top'), whether they are fuels of a different grade or fuels of the same grade but from a different source, needs to be avoided if at all possible; complete segregation of different bunker stems is the primary objective.

However, it is accepted that there will be some occasions where, for whatever reason, complete segregation is not possible. This section provides guidance on maximizing available tank ullage, and, in cases when it is necessary to commingle, aims to minimize the risks of mixing potentially incompatible fuels.

Forward planning is key to mitigating the risk of creating an unstable fuel in the ship's bunker storage tanks through the commingling of incompatible fuels. This forward planning begins with advanced bunker order management and fuel consumption planning at the previous load port; for example, while it is tempting to take maximum advantage of discounted fuel, doing so may well result in an inability to provide empty tank space for segregated storage of all the fuel to be bunkered at the destination port. Good practice dictates that the ship's crew should, ahead of arrival at a port, be fully aware of the quantities and qualities of fuel in each tank as well as in the transfer pipework.

Maximizing available ullage when only a small quantity of 'old' bunker fuel remains on board

Prior to loading new bunkers, the fuel levels in the onboard tank(s) destined to receive a new bunker stem should be lowered as far as practicable (i.e. to just above suction if possible)—effectively emptying the tank. This can be achieved by bulking together the remaining quantities from the same bunkering to the fullest extent possible, allowing a new bunker stem to be loaded into the (effectively) empty tanks. It is accepted that there will still be some remaining product from the previous stem in the heel of the tank(s). It is also recognized that, for ship stability or other reasons, it may not be possible to empty bunker tanks during the voyage, but the goal should be to ensure that there is sufficient ullage in the other tanks to enable the proposed receiving tank(s) to be effectively emptied by internal transfer operations after arrival at the destination port and prior to receiving a fresh bunker stem.

¹² Refer to ISO/PAS 23263:2019, *Petroleum products—Fuels (class F)—Considerations for fuel suppliers and users regarding marine fuel quality in view of the implementation of maximum 0.50% S in 2020*. Annex D: 'Commingling of fuels'.
<https://www.iso.org/standard/75113.html>

Another useful pre-bunkering tactic to help ensure that an empty receiving tank is available is to ensure that the transfer pipework is full. Once the ship is safely moored, the settling tank could also be filled.

Note: under no circumstances should any tankage be filled above the respective high-level alarm limits. If it is not possible to empty all the intended bunker tanks, the ship will be in a commingling situation and, if this has not been previously recognized (see below), spot and possibly TSP testing will need to be undertaken. The most representative test sample is likely to be obtained during transfer from the bunker tank to the settling tank. It is also necessary to get a representative sample, from the bunker supplier, of the actual fuel to be supplied, bearing in mind that the only truly representative sample of that fuel will be the drip sample at the flange at the time of bunkering—which, of course, has not yet been undertaken.

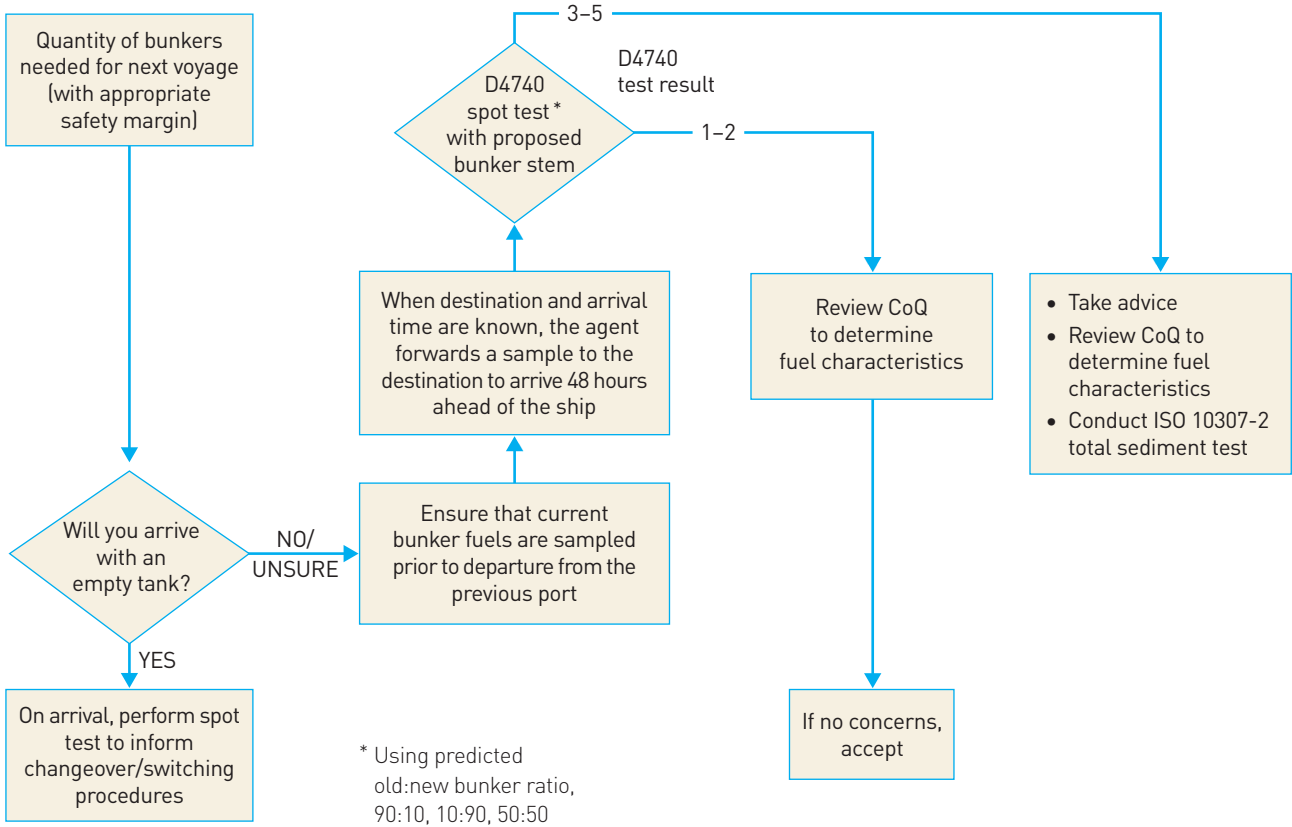
If empty bunker tanks are available, the issue of compatibility testing becomes less significant, although the spot test (ASTM D4740) should still be performed as this may help the ship's crew during subsequent operations such as fuel switching, or when there is a need to bulk fuels for new bunker preparations and/or transfers for ship stability purposes. At all times, it should be remembered that fuel from the previous bunker delivery will still be present in the transfer pipework.

Test methods for compatibility will be the same beyond 1 January 2020 as they are at present, although improvements in the existing methods and developments of new approaches continue to be explored. However, an assessment for potential incompatibility involves more than just testing, and starts with examination of the fuel characteristics of proposed bunkers to determine the 'nature' of the fuel (see *Fuel as supplied: identification of quality* on page 30). A key point to remember is that the ASTM D4740 spot test, while still a valid quick and easily undertaken onboard test, can return 'false positives' (apparent deposition which mimics the spot patterns and would indicate fail ratings) with waxy/paraffinic fuels; such a result would, however, be on the safe side. If a spot test result requires validation, the compatibility of the fuel should be further checked using a more thorough and robust test, e.g. the laboratory-based total sediment (aged) test ISO 10307-2 Procedure A, Total Sediment Potential (TSP) (thermal ageing). This is the referee test method defined in ISO 8217:2017 and takes 24 hours to complete; it is therefore impractical to use while the bunker supplier is waiting to deliver the bunker stem.

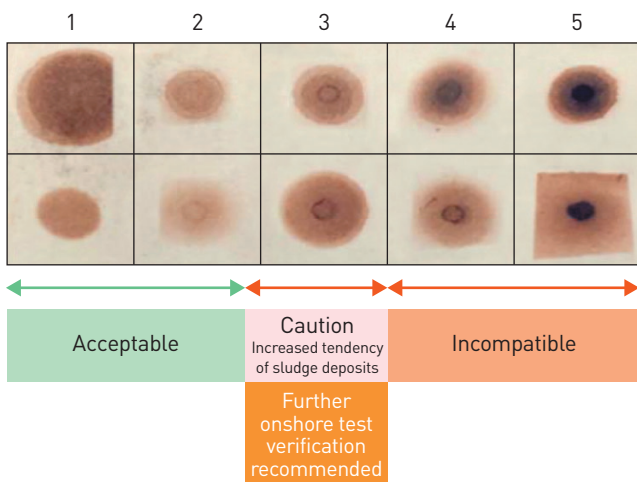
From the supplier's perspective, if the ship is unable to take delivery of the nominated fuel, either in full or in part, this can create scheduling/operational problems for barge operators, potentially incurring costs which can be substantial. Thus, effective and advanced fuel order management and fuel consumption planning to ensure that products are received into segregated tankage to avoid commingling are vital to minimize the risk of such situations arising.

If the ship is unable to receive a bunker stem into an empty tank, and commingling is unavoidable, the risk of incompatibility will be a concern. This could be resolved by the ship sending a sample of the fuel to be commingled, prior to arriving at the port, for compatibility testing to ensure that it is compatible with the fuel that is scheduled to be delivered. If the test indicates incompatibility, the scheduled delivery can be cancelled in advance of the ship's arrival in port.

Figure 1 Example of the steps that could be followed during a bunker delivery
(a high-level scheme more suited to those situations where segregated bunkering is the norm and the ship may unexpectedly have to commingle)



* ASTM D4740 spot rating¹



Reference spot description (source: ASTM D4740: 2019)

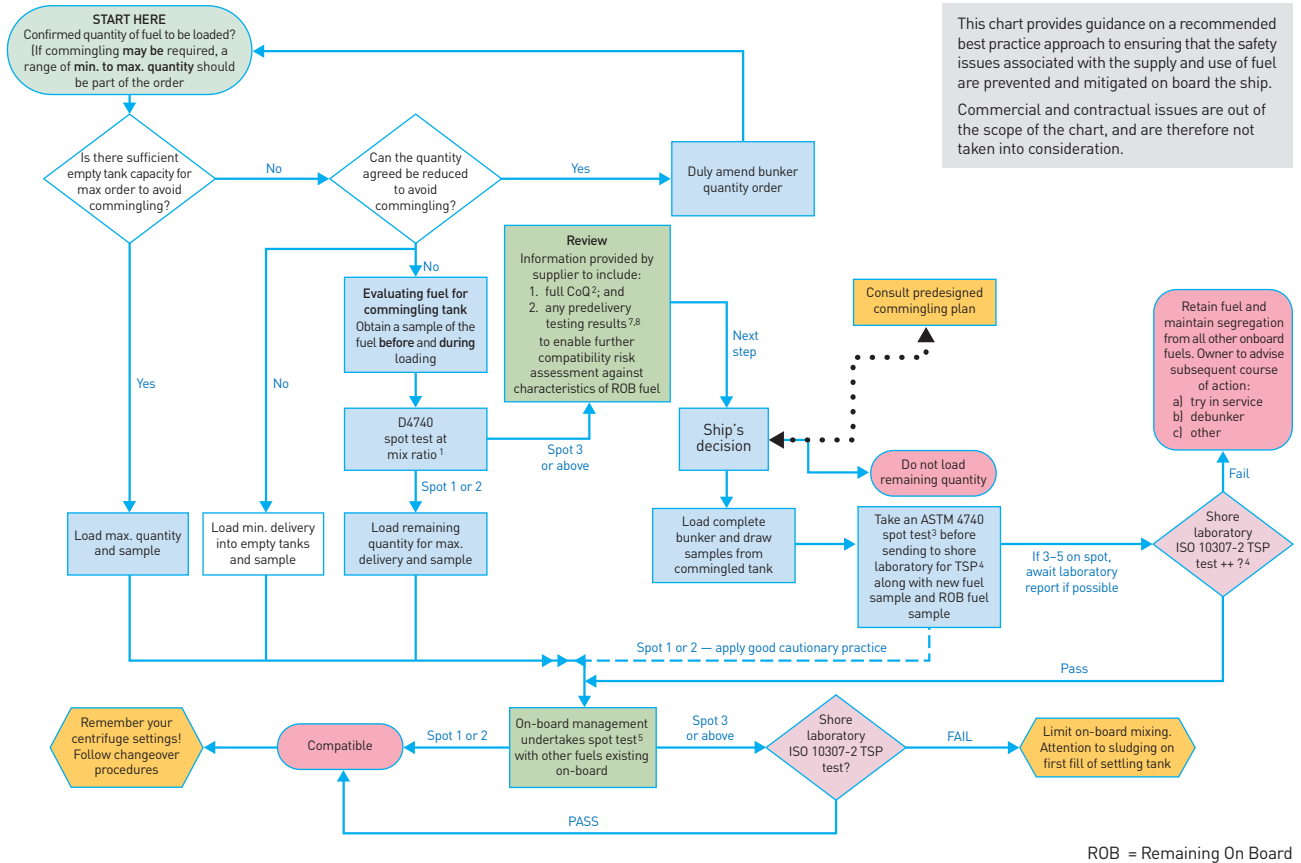
Characterizing features according to spot number:

1. Homogenous spot (no inner ring).
2. Faint or poorly defined inner ring.
3. Well-defined thin inner ring, only slightly darker than the background.
4. Well-defined inner ring, thicker than the ring in reference spot no. 3 and somewhat darker than the background.
5. Very dark solid or nearly solid area in the centre; the central area is much darker than the background.

Note

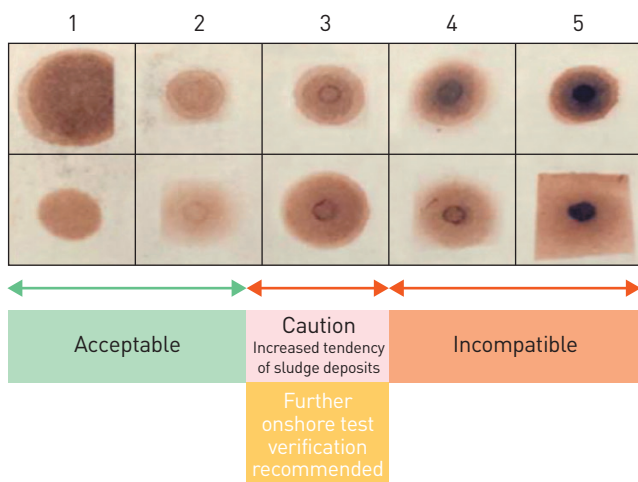
1. Where a spot rating is difficult to determine, i.e. whether the rating is '2' or '3', the higher rating number should be reported.

Figure 2 Example of the steps that could be followed during a bunker delivery
(a more detailed example which caters for additional eventualities)



ROB = Remaining On Board

* ASTM D4740 spot rating⁶



Reference spot description (source: ASTM D4740: 2019)

Characterizing features according to spot number:

1. Homogenous spot (no inner ring).
2. Faint or poorly defined inner ring.
3. Well-defined thin inner ring, only slightly darker than the background.
4. Well-defined inner ring, thicker than the ring in reference spot no. 3 and somewhat darker than the background.
5. Very dark solid or nearly solid area in the centre; the central area is much darker than the background.

Notes

1. Mix ratio should be approximately that of the intended commingling ratio (new, old and test: 10:90 / 90:10 / 50:50) to have a wider picture of mix behaviour.
2. CoQ completed: to include minimum requirements of viscosity, density (CCA may be calculated), micro carbon residue (MCR), pour point, sulphur; further analysis and other operational parameters may be included. Requires support from suppliers.
3. This will be a single fuel spot test of a sample from a commingled fuel tank (if possible; if not possible, move straight to outcome assumption of spot 3-5).
4. TSP—signifies a full laboratory-based compatibility/stability assessment programme which may require the full 24-hour test programme to achieve a definitive result.
5. New bunker compatibility check with bunkers remaining on board, using 50:50, 10:90 and 90:10 spot checks to facilitate on-board transfer and use.
6. Where a spot rating is difficult to determine, i.e. whether the rating is '2' or '3', the higher rating number should be reported.
7. Some ships may be in a position to forward samples for pre-bunker analysis compatibility checks, requiring close cooperation with the suppliers.
8. ASTM D4740 spot test to be requested from the supplier if multiple batches of the same fuel grade are delivered from multiple tanks.

Pre-delivery information should also be requested from the supplier to provide information on the variable characteristics of the proposed bunkers, such as viscosity, density, pour point and micro carbon residue (MCR). Two fuels that have widely differing characteristics of viscosity, density, pour point or MCR, would suggest that they are less likely to be compatible. Fuels that have generally similar characteristics are more likely to be compatible. This characteristic assessment does not replace the need to carry out a physical compatibility test at the expected commingling ratio, before mixing.

Reference should be made to Figures 1 and 2 on pages 38 and 39, respectively, which provide examples of flow charts that could be adapted and developed in house to guide the decision-making process. Please note that these are simply examples of possible steps that could be followed before and during a bunker delivery. Figure 1 is a simplified scheme more suited to situations where segregated bunkering is the norm and the ship may unexpectedly have to commingle. Figure 2 is a more comprehensive scheme which caters for all eventualities.

Summary of requirements (best practice/risk mitigation)

Do:

- Avoid mixing bunker fuels: if possible, receive new fuels into empty tank(s).
- Carry out the spot test first on the proposed mixture if you arrive in port without an empty tank to load into; if that fails, take advice and/or confirm with the TSP test to confirm whether there are potential issues if products are mixed.
- Purchase fuels with similar viscosities and densities where possible.

Do not:

- Mix a residual fuel oil with a marine diesel oil (MDO) or marine gas oil (MGO).
- Mix fuels with greatly dissimilar viscosity, densities, MCR or pour point; dissimilar characteristics may provide an early indication of possible incompatibility.

Preparing hardware and systems for the expected range of max. 0.50%-sulphur fuels

The challenge for a ship's crew in using max. 0.50%-sulphur fuels will be in ensuring that the ship's equipment is appropriately prepared, and the systems arranged to manage each batch of fuel with potentially different physical characteristics. The fundamental principles for this are no different to those that apply to the different types of fuel that the ship has used since entering service. However, the expected variability of the max. 0.50%-sulphur fuels that will be available will require that much greater attention is paid to aspects of storage, handling, treatment and combustion than might have been necessary in the past.

The most obvious point is that where engines have been set up to use residual fuels in the past, this will have been carried out on the basis of an expectation that fuel sulphur content would typically be in the range of 2.00–3.50%. With the use of max. 0.50%-sulphur fuels, the neutralizing demand on the engine lubricants and cylinder oil will be dramatically reduced. If the oil's base number (BN) is too high, this generally leads to serious operating problems. Consequently, shipowners should engage with their lubricant suppliers and follow OEM guidelines to ensure that the most appropriate lubricants are being used.

The non-combustible residue of an oil's detergent additives can lead to the formation of high levels of ash deposits, which can cause:

- ash deposit build-up on pistons and valves;
- loss of oil stability;
- polishing of cylinder liner bores;
- valve guttering;
- loss of power;
- increased consumption of lubricating oil; and
- increased fuel consumption.

There may be occasions when a ship will need to receive a distillate fuel, rather than its usual residual-based max. 0.50%-sulphur fuel (possibly because of local availability issues). In such cases, consideration should be given to the potential transfer of heat between adjacent storage tanks—either from a residual-based fuel with a relatively high transfer temperature requirement, or from a high pour-point distillate fuel, to an adjacent distillate fuel without any minimum temperature requirement. This situation will need to be managed by careful planning of fuel storage and may require some internal transfer of fuels between storage tanks prior to bunkering.

The characteristics of fuel in the storage tanks will need to be tracked and recorded to minimize the risks of commingling fuels with differing characteristics. Some of the max. 0.50%-sulphur fuels may have a relatively high pour point, and it is important that the fuel is maintained at a temperature above its pour point in the storage tanks to prevent wax deposition. In contrast, some other max. 0.50%-sulphur fuels may be supplied at relatively low viscosities, and in such cases limiting the temperature may be necessary to ensure pumpability.

Since wider variations in density could be expected compared to those previously experienced, the selection of gravity discs for fuel oil purifiers will need more careful consideration to ensure that the correct location of the fuel/water interface is maintained, otherwise the efficiency of separation will be affected. Guidance provided by the purifier manufacturer should be followed when selecting the appropriate gravity disc for a new batch of fuel.

A major consideration will be the ability of the pre-injection viscosity control system to properly respond to the viscosity of the fuel being used. In the past, the range of temperatures required will generally have been quite narrow due to the usual range of actual viscosities of the fuels bunkered. With the range of viscosities now expected, the automatic functioning of such arrangements will be crucial; this will have an impact on specific aspects such as the stem of the heat control valve—e.g. can the valve stem still travel over its full range or, due to past limited requirements for the valve to operate to its full extent, has it become so severely 'necked' as to prevent movement over the full range as may now be required?

The ship's crew will still need to pay attention to the rate of change of fuel temperature when switching from one fuel type to another. The injection temperature required for different batches of max. 0.50%-sulphur fuel may differ considerably, and it is essential that the ship's engineering crew always ensure that engine operations remain within the engine builder's limits regarding the rate of temperature change. When using a distillate-based fuel, it may be necessary to switch off any trace heating on fuel lines—and to ensure that the shut-off is indeed effective—as well as ensuring that, due to the proximity to other heat sources, there is no inadvertent heating of such fuels.

Of all the aspects to be considered, the principal point that should always be checked when using a fuel of lower viscosity than usual is whether the engines' (main and auxiliary) fuel oil injection systems are fully capable of operation. Due to the injection viscosities of residual fuels used in the past, these systems may have masked the effects of wear on the fuel pump plungers and injectors. However, switching to a lower viscosity fuel presents the risk that excessive leakage will either limit the power that can be developed and the responsiveness to load change demands or, in extreme cases, even cause an engine to stop or fail to restart. Where such lower viscosity max. 0.50%-sulphur fuels are used, it is strongly recommended that the starting and load acceptance of a hot engine are checked while in a safe location—it is essential that any potential problems are identified prior to manoeuvring.

Switching between fuel parcels—diesel engines

Prior to operating a ship with multiple grades of fuel and switching between them, a design evaluation should be carried out to ensure that all of the equipment on board is suitable and capable of being operated safely and effectively with regard to the wide range of fuel parameters that may be encountered.

Classification societies have specific requirements that apply to the fuel switching process, and any modifications made to the fuel oil system and engine components should be communicated to them and approved.

Ships that are operating both inside and outside of the ECAs will already be set up, and the crew will be familiar with the system design and procedural processes required for the switching between 0.10%-sulphur MGO and high-sulphur fuel oil (HSFO). The replacement of HSFO with a max. 0.50%-sulphur fuel will require additional considerations, both technical and procedural, to manage the potential variability of the max. 0.50%-sulphur fuels ranging from the familiar higher-viscosity fuels of 380 cSt down to the low viscosity of a distillate grade. In view of this, the functions of the fuel handling systems, from storage through treatment, conditioning and combustion, will need to be assessed for their adaptability and responsiveness to such a variance, primarily with regard to heating control and fuel pump viscosity rating and wear condition.

Consideration will further need to be given to the redesignation of storage tanks to accommodate 0.10%-sulphur and 0.50%-sulphur fuels (DM and RM) or, where EGCS are fitted, 0.10%-sulphur (DM only) and HSFO (>0.50% sulphur).

The design evaluation should identify potential hazard scenarios associated with aspects of the proposed modifications. The various properties of the intended grades of fuel oil should be considered along with the possible issues associated with on-board processing of these fuels, the fuel switching process, compatibility between various fuels, engine start difficulties and other relevant issues. The evaluation should cover fuel switching between different grades of fuels, and the issues and dangers that are associated with switching over while manoeuvring, during long idle times and while starting engines in port. Potential hazards include, but are not limited to, loss of propulsion, blackouts, failure to start the engine, and fire and explosions.

The issues related to fuel switching are unique to each ship and its condition, so there are no universal procedures that can be applied to all, or even most ships. However, there are certain general principles and procedures that apply to the majority of ships, and understanding these will be helpful in developing the fuel switching procedure for any specific ship.

The ship operator should establish procedures, plans and instructions, including checklists as appropriate, for key shipboard operations concerning the safety of the personnel, ship and protection of the environment. The various tasks should be defined and assigned to qualified personnel. For ships that have never entered an ECA or changed over fuels, this needs to be practised in advance.

Any new crew members joining a ship should be familiarized and trained before participating in the fuel switching process. The proper implementation of fuel switching and reliable operation of the propulsion machinery during switching and while operating on the different grades of fuel is essential. This is particularly the case if switching is being carried out close to ports and coastal waters where there is the greatest risk to the ship and the environment from loss of, or reduction in, the ship's propulsion power. Great care should be taken when switching fuel so as to avoid situations that may jeopardize the safety of the ship, e.g. by considering the distance to the coastline and the density of traffic.

Preparing the fuel switching procedure

A number of important issues will need to be addressed when preparing the fuel switching procedure:

1. An assessment of the fuel system on board the ship will need to be carried out to determine what actions need to be taken to ensure the safe and effective operation of the ship using the various grades of fuel.
2. The fuel storage, settling and service tank arrangement should be assessed; this will determine the extent of commingling between fuels during the fuel switching procedure. Segregating fuels is the preferred approach as this may allow for quicker switching and reduces the potential for compatibility issues. The recommendation is therefore to have separate fuel storage, settling and service tanks. Due to the requirements of SOLAS, most ships built after 1998 have double service tanks and more than two storage tanks, so the possibility for segregation exists.
3. If the ship does not have a tank arrangement that permits segregation of fuel beyond the storage tanks, procedures for fuel mixing will need to be developed. One way to approach this is to reduce the level of fuel in the settling tank to as low as possible without losing suction before filling with the alternate fuel. A significantly longer duration of operation may be required to complete the fuel switching using this approach.
4. Prior to starting fuel switching, it is generally recommended that the ship's power be reduced to the level specified in the fuel switching procedure. Typically, this may be a power level of 30 to 70% of the maximum continuous rating (MCR), depending on the specifics of the propulsion plant.
5. Avoiding thermal shock to the fuel system is a critical element for consideration in a fuel switching procedure. Engine manufacturers normally offer guidance on the maximum allowed rate of temperature change in fuel systems, such as the commonly used rate of 2°C/minute. This will have an impact on the time it will take to complete the fuel switching process. For example, if a ship is using HFO heated to about 150°C prior to the fuel injection pumps, and is switching to MGO at 40°C, the temperature difference is about 110°C. Under these conditions and considering a 2°C/minute permitted rate of change, the temperature reduction from 150°C to 40°C during the fuel switching process should take a minimum of 55 minutes to complete safely. However, it may be prudent to use a longer period than the minimum calculated time so that short-term rapid temperature changes are avoided during the process, which may not consist of smooth, even temperature changes.

Extending the duration of the fuel switching process to control the rate of temperature change can present a number of challenges, as summarized as follows:

- On many ships, carrying out fuel switching is achieved by manually operating a single three-way valve. This operation changes the fuel source immediately, and if the fuel switching is undertaken at high power levels the fuel change will be carried out in a relatively short period of time as the fuel circulates at a high rate through the mixing tank. A fast changeover from HFO to MGO can lead to overheating of the MGO, causing a rapid loss of viscosity and possible gassing in the fuel system. Too rapid a change from unheated MGO to HFO can lead to excessive cooling of the HFO and excessive viscosity at the fuel injectors, again causing loss of power and a possible shutdown. If a single switching valve is provided, it is recommended that fuel switching is carried out with the engine at low power levels, typically between 30 to 70% MCR, so that the fuel change occurs gradually enough to remain within the temperature rate-of-change limits. For fuel switching to be carried out at higher power levels, the fuel switching system may need to be modified; this may involve the installation of an automated fuel switching system that changes the fuel in a timed and regulated manner. Such automated systems are offered by some engine makers and fuel system equipment suppliers.
 - When switching from heated HFO to MGO, engine components and fuel in the mixing tank will retain heat during the switching process. As the still-hot fuel mix becomes purer MGO, there is real danger of 'gassing' at the booster pumps causing the engine to stop. The fuel temperature should therefore be monitored closely during this process, and components given sufficient time to cool down before running the engine on pure MGO. Fuel coolers or even chillers can be of value in such circumstances.
 - When changing over to a low-viscosity fuel, fuel heaters and pipe heat tracing should be turned off in a controlled manner during the fuel switching process. Most ships have a viscosity control system that controls the heat supply to the fuel preheaters located in the fuel supply system. This system will adjust the heat supply to the preheaters as the fuel viscosity changes during the fuel switch.
6. If a fuel cooler or chiller is installed, it should be turned on and the valves to the cooler opened carefully while closely monitoring the temperature of the fuel to prevent an excessive rate of cool-down. When changing from cooled MGO to heated HFO, the cooler can usually be bypassed and shut off at the start of the process.
 7. As discussed previously, the potential for incompatibility of the mixed fuels may present certain challenges (see *Compatibility issues* on page 22). It is therefore essential that, during the fuel switching process, the pressure difference across fuel filters, strainers and the mixing tank should be carefully monitored for evidence of clogging and the formation of excessive sludge. This is one reason that fuel switching is best done ahead of time in open waters and clear of hazards.
 8. Purifier systems should be adjusted as appropriate for the new fuel. It is important to make sure that the suction and return pipes go to the correct tanks. If operating on MGO, a separate purifier may be put in operation.
 9. If the engine incorporates fuel valve injector cooling, this may need to be turned on or off, as appropriate, during fuel switching. For example, after switching to MGO, fuel valve injector cooling may not be needed; if this is the case, and if the engine will be operated on MGO for extended periods of time, injector cooling should be turned off to prevent overcooling of the fuel. If cooling was turned off prior to switching to heated HFO fuel, it will need to be turned on again. It is important to consult with the engine manufacturer regarding this item.

10. It is essential that the temperatures of the engine and its components are monitored to ensure that they are maintained at normal service temperatures. Engine control equipment such as control valves, temperature sensors, viscosity controller, etc. should be adjusted or reset as necessary to account for the new fuel type, unless this is carried out automatically. As experience is gained with fuel switching, there will be improved understanding of what needs to be adjusted and monitored during the switching process and during sustained operation with different fuels. During initial fuel switches, vigilance is needed to spot potential problems before they become serious. Fuel switching procedures should be adjusted to account for identified problems.
11. Once the propulsion and generating plant are stabilized on the new fuel, and all components are at normal service temperatures, it should be possible to bring the propulsion plant back to normal power to enable the ship to proceed into restricted and port areas.
12. It is advisable to contact the lubricant supplier and follow OEM guidelines to determine the recommended feed rate and base number of the lubricant, to ensure that the appropriate degree of cylinder lubrication is maintained.

It is recommended that, after prolonged running with MGO, lube oil samples from both the main engine and diesel generators are tested in a laboratory to determine possible leakage of fuel into the crankcases.

The use of max. 0.50%-sulphur fuel in boilers

Reference in this document to boilers means the main high-pressure boilers used primarily onboard LNG ships for their propulsion steam turbines, and the auxiliary medium pressure boilers used mainly on tankers for cargo tank heating and cargo pump operation. The main boilers onboard LNG ships were originally designed based on dual fuel firing with both HFO and heated LNG vapour.

Important: Where boiler equipment manufacturers have issued specific guidance on the use of distillate fuels, as opposed to residual fuels, that guidance *must* be followed. For boiler combustion systems this may include, but is not limited to, aspects such as the size and specification of burner fuel supply pumps, positioning of burners, type of burner lance and tips, flame eye/scanner type and positioning, and guidance on purge duration, combustion control settings and burner management systems including sequences for purging/re-lighting of boiler flames. Initial set-up and commissioning of boiler installations and retrofits for a different fuel should be carried out by qualified personnel, with approval by the ship's classification society. Subsequent to set-up and commissioning, the ship's engineering crew should be thoroughly trained in the start-up, operation and shut-down procedures with the new fuel, as well as in any maintenance routines that are, or might be, required. As established during the set-up and commissioning, the procedures involved, complete with details of the final settings, should be properly documented in the machinery operating manual.

General considerations: use of distillate-type fuels

Firing a boiler with MGO/MDO should not be a problem as long as the correct safety precautions have been taken; most boilers were originally designed for operation on HFO with MGO/ MDO only as a start-up fuel (from dead ship). Prolonged operation using MGO or VLSFO/ULSFO for the main boilers would require an independent fuel piping system with dedicated supply pumps of the right size and specification cross-connected to the original burner fuel rail.

Prevention of unburned fuel in the boiler furnace

Due to the volatility of MGO, it is extremely important to ensure that no gases are allowed to form in the furnace or in the pipelines.

Preventing fuel from entering the hot furnace when no flame is present is a primary safety consideration. Ensuring that all valves are in good operational condition is also of critical importance. In the unforeseen event that unburned fuel enters the hot furnace, gases will form and create a potential risk of furnace explosion.

Pre-purging and post-purging of the furnace at certain pre-determined time durations in accordance with the burner management sequences are therefore the most important consideration when using MGO as the main fuel. The pre-purging of a furnace is normal practice for all fuels, but if the boiler furnace has previously been fired with MGO, and for some reason the flame is extinguished, a post-purge will also be required.

It should be common knowledge that a furnace needs to be pre-purged before any fuel firing. When using MGO, it is even more important to ensure that, in an emergency firing mode (i.e. local manual operation), operators do not attempt to start the burner without taking the purging time into consideration. In particular, after a failed attempt to establish the first flame, it is of extreme importance that proper pre-purging of the furnace is performed, with the forced draft fan (FDF) dampers in the fully opened position.

It is equally important to ensure that no gasification of the fuel takes place in the piping system leading to the boiler burners. Precautions must be taken to protect the piping systems against any potential heat sources which might increase the temperature of the fuel to above its auto-ignition temperature.

Particular attention needs to be paid to the following areas of concern:

- **MGO/VLSFO/ULSFO boiler fuel supply pump:** in most fuel systems, the fuel supply pump is oversized to ensure that enough fuel is supplied to the burners. This results in a large amount of fuel going through the pump. As the pump is a gear pump, friction will heat up the fuel within the pump. When the surplus fuel is circulated over a smaller circuit, this can potentially increase the fuel temperature to above the auto-ignition temperature.
- **Burner:** in the case of a steam-atomizing burner, the design of the burner lance should be such that the steam has a minimal temperature-raising effect on the fuel during operation. When the burner is idle, the burner should not be filled with fuel.
- **Fuel line:** care needs to be taken to ensure that no heating source is present near the boiler fuel supply piping system.
- **Setting up:** approved changeover procedures must be followed to ensure that the boiler fuel supply and its recirculating line are correctly set up to avoid cross-contamination of fuels.

Combustion concerns

MGO has a lower density and a higher calorific value compared to HFO, which affects the combustion process and resultant heat transfer. The appropriate choice of burner and tip, coupled with adjustments to combustion control settings, are required to ensure that optimum boiler performance is achieved throughout the range of boiler load variations, especially for the main boilers onboard LNG ships. The combustion controls for main boilers are automated to cater for large and rapid load changes, particularly during manoeuvring conditions.

MGO does, however, burn with a different light spectrum, and care needs to be taken to ensure that the correct flame detection equipment (flame eye) is used. It is vital that the flame eye is set up correctly to detect the flame within the set time frame upon operation of the burner ignitor and admission of fuel. In the event of a flame failure, the flame eye must initiate to close the fuel supply valve and shut down the fuel supply to the burner, and should prevent the opening of the fuel supply valve until the correct burner management system sequences have been restarted.

A further combustion concern is related to a potential increase in smoke density during load variations as the lower viscosity of MGO will cause changes in fuel demand that will be different from those specified in the original design based on using HFO and/or LNG vapour. The air/fuel ratio settings will therefore need to be adjusted accordingly.

Viscosity

Due to the low viscosity of MGO, extra care needs to be taken with regard to the tightness of shut-off valves. Furthermore, the boiler fuel supply pumps should be MGO-ready (taking into account the reduced lubrication capabilities of the MGO).

Note: In the case of more recently built LNG ships (ordered after 2010), the precautions recommended above for boilers will likely have been taken into consideration. For LNG ships that have yet to be retrofitted, the need to observe the precautions discussed above will require adjustments to be made in the system.

Use of very-low-sulphur HFO and ultra-low-sulphur HFO

The main issue with very-low-sulphur HFO and ultra-low-sulphur HFO is the variability/lack of uniformity between different fuels on the market. It is not known how fuels from different suppliers (or bunkering ports) will react with each other.

This variability may also result in boiler combustion that is not optimal for all fuels, hence care will need to be taken to ensure that fouling of the boilers is not excessive. If the fuel leads to excessive fouling, the burner/combustion settings will need to be adjusted as a temporary measure until there is an opportunity to shut down the boiler to clean the burner swirler and associated burner fittings in the furnace. Consultation with specialized experts should be considered for assistance when making these adjustments.

When these fuels are used in combination with MGO, it is recommended that consideration be given to the use of separate day tanks and the continuation of the fuel changeover procedures, with the ideal solution being the use of separate fuel lines to the burners for MGO and other fuels.

For blended fuels in particular, it is **extremely important to study the BDN and Fuel Analysis Report carefully**. The original equipment manufacturers should always be contacted if there is any question as to whether the fuels will cause problems for the burners/boilers.

Appendix 1:

Definitions

Bunker delivery note (BDN)	A means for the supplier to document the quantity, grade and quality of fuel delivered from a supplier to a customer and provide evidence of receipt of the product, as well as to record information required by MARPOL Annex VI, including, as required by Regulations 14.5 and 18.5, the sulphur value of the product.
Bunker stem	The supply of fuel to a ship on any one occasion.
Calculated Carbon Aromaticity Index (CCAI)	An indicator of the ignition performance of residual fuels in diesel engine applications. CCAI values typically range from 820 to 870; the higher the CCAI value, the greater the possible tendency to poorer ignition performance.
Calorific value	The energy density of a fuel per unit mass, i.e. the heat released when a known quantity of fuel is burned under specific conditions.
Cloud point	Refers to the temperature below which wax forms a cloudy appearance. The presence of solidified waxes thickens the fuel and can clog fuel filters and injectors in engines.
Cold filter plugging point (CFPP)	The lowest temperature at which a given volume of a distillate fuel still passes through a standardized filtration device in a specified time when cooled under certain conditions.
Compatibility	A measure of the ability of two or more fuels to be commingled without evidence of material separation, resulting in the formation of multiple phases, e.g. flocculation or separation of asphaltenes.
Fuel	Any distillate or residual fuel intended for combustion purposes for propulsion or the operation of systems on board a ship.
Fuel oil non-availability report (FONAR)	The means by which a ship notifies its Administration and the competent authority of the port of destination of the non-availability of compliant fuel, in accordance with the requirements of MARPOL Annex VI, Regulation 18.2.
Fuel switching/ fuel changeover	The procedure carried out by a ship which is required to change the fuel in use to a fuel with a different sulphur content when entering or leaving a different sulphur emission control area (ECA).
ISO 8217 (<i>Petroleum products—Fuels (class F)—Specifications of marine fuels</i>)	International standard that specifies the requirements for fuels intended for use in marine diesel engines and boilers, prior to conventional on-board treatment (settling, centrifuging, filtration) before use. Unless otherwise stated, the latest edition of the standard applies (ISO 8217:2017).

Quality Management System (QMS) A set of internal rules that are defined by a collection of policies, processes, documented procedures and records, to be certified in accordance with internationally recognized standards (ISO 9001 or equivalent). In the context of marine fuels, such a system defines how a company will achieve the creation of the marine fuel product and the delivery to its customers, and provide evidence of its origins, intermediate treatment or processing/blending and conformance with appropriate standards.

Stability A measure of the resistance of a residual fuel to break down and precipitate asphaltenic sludge despite being subjected to forces, such as thermal and ageing stresses, while handled and stored under normal operating conditions.

Fuel definitions

Distillate marine (DM) fuel oils Fuel oils as specified in ISO 8217:2017, Table 1, including DM fuel grades DMA, DMZ, DMB and DMX, and DF (distillate FAME) fuel grades containing up to 7% FAME, i.e. grades DFA, DFB and DFZ.

High-sulphur fuel oil (HSFO) Fuel oil with a sulphur content exceeding 0.50% (e.g. HSFO, mainly RM).

Residual marine (RM) fuel oils Fuel oils as specified in ISO 8217:2017, Table 2

Ultra-low-sulphur fuel oil (ULSFO) Fuel oils including RM and DM fuels with a maximum sulphur content of 0.10%.

Very-low-sulphur fuel oil (VLSFO) RM and DM fuel oils with a maximum sulphur content of 0.50%.

Other terms that may be in use

Heavy fuel oil (HFO) A general term used to represent RM fuel grades as specified in ISO 8217:2017, Table 2.

Low-sulphur fuel oil (LSFO) A general term used for lower-sulphur fuel oils such as those with a maximum sulphur content of 1.50% and 1.00%, neither of which will be applicable after 1 January 2020.

Marine diesel oil (MDO) A general term used to represent DM fuel grade DMB, and DF fuel grade DFB, as specified in ISO 8217:2017, Table 1. May contain traces of residual fuel elements.

Marine gas oil (MGO) A general term used to represent DM fuel grades DMA, DMX and DMZ, and DF fuel grades DFA and DFZ, as specified in ISO 8217:2017, Table 1. More specifically, clear and bright in appearance, notwithstanding the use of dyes, and containing no residual fuel material.

Appendix 2:

Key fuel quality characteristics and the significance of off-specification test results

The following table provides a brief on the potential significance of some of the key fuel characteristics mentioned in this document and also specified in ISO 8217:2017, Tables 1 and 2, along with the implications of being off-specification. It should be noted that this is not an exhaustive list but rather provides an indication of some of the possible outcomes of an off-specification product being supplied to a ship.

Distillate fuel—significance of the fuel characteristics listed in ISO 8217:2017, Table 1

Characteristic	Significance	Implications of off-specification
Viscosity at 40°C	Ease of flow	<p>Values below the minimum limit are normally a concern for distillates: there is potential for insufficient dynamic lubrication under higher temperature conditions. There is increased tendency to flow through fine clearances, particularly under the high pressures of fuel injection pumps, especially where those clearances have increased due to wear, resulting in an inability to generate the required pressure/flow. Can also lead to a shortfall of spray penetration on injection.</p> <p>Receiving a distillate with a viscosity value above the maximum limit as ordered is extremely rare for a distillate; however, if this occurs it could compromise the injection spray pattern and lead to an increased mechanical load on fuel pumps and drive arrangements.</p> <p>Suitability is dependent on combustion machinery requirements. Response: apply cooling or heating, as applicable.</p> <p>Ensure that the bunker order has highlighted any minimum and/or maximum viscosity requirements.</p>
Density at 15°C	Weight/volume relationship of a fuel	<p>Reduced tendency for settling out of water and solids, although this is more of an issue for the higher-density residual fuels due to the naturally lower densities of distillates.</p> <p>As density is generally used to convert the delivered quantity (m³) to the invoiced amount (tonnes), a value below that quoted on the bunker delivery note will result in a tonnage shortfall.</p> <p>The gravity disc selection for a purifier may need to be changed to match the density of the fuel.</p>

Distillate fuel—significance of the fuel characteristics listed in ISO 8217:2017, Table 1 (continued)

Characteristic	Significance	Implications of off-specification
Sulphur	<p>SO_x emission control. Controlled to limit SO_x and related particulate emissions for environmental protection.</p> <p>Precursor of post-combustion low temperature corrosion of susceptible components in the engine and exhaust duct.</p>	<p>Statutory issue. Non-compliance with MARPOL Annex VI, Regulation 14 (and/or local controls).</p> <p>For two-stroke engines, ensure that suitable cylinder liner oil is on board to address the anticipated sulphur content of the fuel to be used. Adjust feed rates as applicable.</p>
Flashpoint	<p>The temperature at which fuel vapour is ignited under specific closed-cup test conditions.</p>	<p>Statutory issue. Non-compliance with SOLAS. Values substantially below the minimum limit could indicate inclusion of particularly volatile components with potential for evolution of hydrocarbon-rich vapours. The SOLAS agreement specifies that the flashpoint for all fuels used on board ships should be a minimum of 60°C, except where:</p> <ul style="list-style-type: none"> • allowed otherwise in SOLAS II-2, Regulation 4 which permits fuel oil with a minimum flashpoint of 43°C to be used in certain applications and under controlled conditions; or • a ship is certificated in accordance with the provisions of the <i>International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels</i> (IGF Code). <p>If low flashpoint, report to Class or Flag and/or Flag Administration for guidance.</p>
Acid number	<p>Indicator of acidity; however, there is no direct correlation between acid number and corrosion risk.</p>	<p>See page 19 in this guidance document for more details on this parameter.</p> <p>Where unusual acid number readings are recorded, further investigative analysis may be carried out to determine the cause and whether naturally occurring or not.</p>
Carbon residue (DMB)	<p>Indicator of tendency for formation of post-combustion carbon deposition; significance depends on engine design and operating profile.</p>	<p>In cases of extreme exceedances, which are rare for distillates, there is a tendency for increased formation of post-combustion carbonaceous deposits in the engine, system lubricant, turbochargers and exhaust duct, particularly under low load or other non-optimum operating conditions. There is potential for cracking of fuel in uncooled injector tips, resulting in the formation of hard carbon deposits which compromise combustion by adversely affecting the injector spray pattern, resulting in further deposition.</p> <p>A point of note is that, for the most part, ships' machinery is designed to operate both on residual fuels and distillates, and can tolerate relatively high levels of carbon residue. Hence, this is rarely an issue today.</p>

Distillate fuel—significance of the fuel characteristics listed in ISO 8217:2017, Table 1 (continued)

Characteristic	Significance	Implications of off-specification
Cloud point	The temperature at which wax crystals are first evident on cooling.	If operating at temperatures where a proportion of the wax in a fuel begins to form as crystals, albeit they may be dispersed, this may tend to lead to the choking of filters and other fine clearances. Ensuring that the system has enough warming capability, or an anticipated return to warmer ambient conditions, will prevent any adverse outcomes or difficulties associated with emergency engine starts. Any ship constraints should be made clear in the fuel order specification.
Cold filter plugging point (CFPP)	The highest temperature at which a given volume of fuel fails to pass through a standardized filtration device in a specified time when cooled under standardized conditions (applicable only for distillate fuels).	See on <i>Cold flow properties</i> on page 16 of this guidance document.
Pour point	The lowest temperature at which fuel is still fluid under test conditions.	<p>If a fuel essentially solidifies it becomes unpumpable and is not readily brought back to a liquid condition by heating due to its poor heat transfer characteristic. If it is not possible to await return to warmer ambient conditions, the fuel may literally have to be dug or steam lanced out of the tanks and transfer lines, which will need to be physically rodded through/dissembled to remove the solidified fuel. Fuel in tanks with surfaces exposed to ambient (water or air) temperatures below the pour point may form a solid mass on that surface, which can grow to the point where it breaks away to fall through the liquid phase as a solid mass and choke suction connections.</p> <p>See <i>Cold flow properties</i> on page 16 of this guidance document.</p> <p>This issue is addressed in greater detail in the CIMAC Guideline on <i>Cold flow properties of marine fuel oils</i> (https://www.cimac.com/cms/upload/workinggroups/WG7/CIMAC_WG7_2015_01_Guideline_Cold_Flow_Properties_Marine_Fuel_Oils_final.pdf).</p> <p>Maintain storage and handling temperatures at 10°C above the pour point to avoid risk of solidification.</p> <p>Any constraints due to cold ambient conditions/winter zones should be determined.</p>

Residual fuel—significance of the fuel characteristics listed in ISO 8217:2017, Table 2

Characteristic	Significance	Implications of off-specification
Viscosity at 50 °C	Ease of flow	<p>Higher than expected temperatures required for transfer and injection; however, due to the viscosity/temperature relationship, values significantly higher than the limit value result only in limited increases in required temperatures (i.e. viscosities of 500 cSt and 380 cSt increase the transfer and injection temperatures by around 3 °C and 6 °C, respectively).</p> <p>If the pre-heat is insufficient, the viscosity may rise above the engine manufacturer’s recommended injection viscosity, which may then result in poor atomization and overloading of fuel injection feed pipes.</p>
Density at 15 °C	Weight/volume relationship of a fuel	<p>Decrease in the density differential, which is the basis for cleaning by settling or purification/separation.</p> <p>Conventional purifiers with a nominal density limit of 991 kg/m³ should be able to function with slight exceedances, albeit less efficiently, taking into account test precision.</p> <p>Modern separators, without a conventional gravity disc can, however, operate up to density values of around 1,010 kg/m³.</p> <p>As density is generally used to convert the delivered quantity (m³) to the invoiced amount (tonnes), a value below the quoted bunker delivery note value will result in a tonnage shortfall.</p>
Calculated Carbon Aromaticity Index (CCAI)	Principally included to control the fuel’s viscosity/density relationship, and hence preclude unconventional blends. Also an empirical indicator of ignition performance.	<p>Tendency to indicate ignition delay problems, which will be more pronounced with lower-viscosity fuels; however, low-speed and most medium-speed engines are not generally oversensitive to such issues.</p> <p>For some higher-viscosity grades this may be a factor which sets blending limits. High values result from an atypical viscosity/density relationship which, for the lower viscosity fuels in particular, may indicate the use of unusual blend components.</p> <p>For further details and recommendations, see the CIMAC guidance document, <i>Fuel Quality Guide—Ignition and Combustion</i> (https://www.cimac.com/publications/wg-publications/cimac-wg07-fuel-quality-guide-ignition-and-combustion.html).</p>
Sulphur	Precursor of post-combustion low-temperature corrosion of susceptible components in the engine and exhaust duct. Controlled to limit SO _x and related particulate emissions for environmental protection.	<p>Statutory non-compliance with MARPOL Annex VI, Regulation 14 (and/or local controls).</p> <p>Increased tendency to cause cold corrosion.</p> <p>For two-stroke engines, ensure that suitable cylinder liner oil is on board to address the anticipated sulphur content of the fuel to be used. Adjust feed rates as applicable.</p>

Residual fuel—significance of the fuel characteristics listed in ISO 8217:2017, Table 2 (continued)

Characteristic	Significance	Implications of off-specification
Flashpoint	Temperature at which fuel vapour is ignited under specific closed-cup test conditions.	Statutory issue. Non-compliance with SOLAS. Values substantially below the minimum limit could indicate inclusion of particularly volatile components with potential for evolution of hydrocarbon-rich vapours.
Acid number	Indicator of acidity; however there is no direct correlation between acid number and corrosion risk.	See Page 19 in this guidance document for more details on this parameter. Where unusual acid number readings are recorded, further investigative analysis may be carried out to determine the cause and whether naturally occurring or not.
Total sediment—aged	Quantification of filterable material present. Indicator of whether a fuel is a blend of compatible components and/or whether it will remain in a stable condition over time or on heating.	Test method has a relatively high 95% confidence margin relative to the limit value (0.10% m/m). In addition, off-specification values are often found to be due to toluene insoluble material and hence, in those instances, are not indicative of asphaltene instability. As a straight filtration test, it is indicative of possible increased sediment in tanks (particularly settling tanks) and during treatment (purification and filtering). However, if fuel is not stable, the resulting asphaltenic sludge precipitated will have a serious adverse effect on treatment effectiveness, resulting in excessive sludge precipitation and, hence, choking of the purifier and filters. Coke formation on heater elements restricts heat transfer, and it may therefore not be possible to achieve the required injection temperature. On injection, the sludge will not be sufficiently atomized, resulting in impingement on liners and, hence, cracking and heavy fouling which can impede the action of piston rings and lead to choking of turbocharger turbine blades.
Carbon residue	Indicator of tendency to post-combustion carbon deposition.	Exceedances for residual fuels are rare; however, with elevated levels, there is potential for an increase in post-combustion carbonaceous deposits in the engine, system lubricant, turbochargers and exhaust duct, particularly under low load or other non-optimum operating conditions. Any system constraints should be made clear in the fuel order specification.
Pour point	The lowest temperature at which a fuel is still fluid under test conditions.	Since most residual fuels require heating (30–40°C) to achieve the required transfer viscosities, there is usually capability for tank heating to address this issue. If a fuel solidifies it becomes unpumpable; furthermore, it is not readily brought back to a liquid condition by subsequent heating due to its poor heat transfer characteristic. With engines now deregulated, and ships often running on slow steaming to reduce fuel consumption and emissions, it is necessary to ensure that the steam capacity from the exhaust boiler can still be maintained to keep the temperature of the fuel above the pour point.

Residual fuel—significance of the fuel characteristics listed in ISO 8217:2017, Table 2 (continued)

Characteristic	Significance	Implications of off-specification
Aluminium + silicon	Indicator of abrasive catalytic fine material being present.	High levels of aluminium + silicon (catalyst fines) are not easily reduced during normal on-board treatment, and can therefore pass through to the engine fuel system where rapid wear of injection system components (fuel pumps, injectors), liners and piston rings may occur. Worn piston rings can eventually break, and the resulting debris can cause further extensive damage to combustion chamber components and the turbocharger turbine.

Appendix 3:

Ship implementation planning for max. 0.50%-sulphur fuels

For information of ship implementation planning for max. 0.50%-sulphur fuels, reference should be made to the following sources:

IMO (2018). *Guidance on the development of a ship implementation plan for the consistent implementation of the 0.50% sulphur limit under MARPOL Annex VI*. Marine Environmental Protection Committee circular MEPC.1/Circ.878.

<http://www.imo.org/en/OurWork/Environment/PollutionPrevention/Documents/MEPC.1-Circ.878.pdf>

ICS, ASA and ECSA (2019). *Guidance to Shipping Companies and Crews on Preparing for Compliance with the 2020 'Global Sulphur Cap' for Ships' Fuel Oil in Accordance with MARPOL Annex VI*. International Chamber of Shipping, Asian Shipowners Association and European Community Shipowners' Associations. <http://www.ics-shipping.org/free-resources/2020-Sulphur-compliance>

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