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| --- |
| Section 1 |

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| --- |
| 14 |

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 make­up 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.

Joint Industry Guidance: The supply and use of 0.50%-sulphur marine fuel

**Section 1** Guidance on fuel characteristics and properties

**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.

Joint Industry Guidance: The supply and use of 0.50%-sulphur marine fuel 15

**Section 1** Guidance on fuel characteristics and properties

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](https://www.cimac.com/cms/upload/workinggroups/WG7/CIMAC_WG7_2015_01_Guideline_Cold__Flow_Properties_Marine_Fuel_Oils_final.pdf)

16 Joint Industry Guidance: The supply and use of 0.50%-sulphur marine fuel

**Section 1** Guidance on fuel characteristics and properties

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.

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.

Joint Industry Guidance: The supply and use of 0.50%-sulphur marine fuel 17

**Section 1** Guidance on fuel characteristics and properties

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).

18 Joint Industry Guidance: The supply and use of 0.50%-sulphur marine fuel

**Section 1** Guidance on fuel characteristics and properties

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.

Joint Industry Guidance: The supply and use of 0.50%-sulphur marine fuel 19

**Section 1** Guidance on fuel characteristics and properties

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 pre­treatment. 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.

20 Joint Industry Guidance: The supply and use of 0.50%-sulphur marine fuel

**Section 1** Guidance on fuel characteristics and properties

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.

**Section 1** Guidance on fuel characteristics and properties

**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.

22

**Section 1** Guidance on fuel characteristics and properties

**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 paraffinicity/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.

23

**Section 1** Guidance on fuel characteristics and properties

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.

24

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**

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| **Characteristic** | **Significance** | **Implications of off-specification** |
| Viscosity at 40°C | Ease of flow | 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.  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.  Suitability is dependent on combustion machinery requirements. Response: apply cooling or heating, as applicable.  Ensure that the bunker order has highlighted any minimum and/or maximum viscosity requirements. |
| Density at 15°C | Weight/volume relationship of a fuel | 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.  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.  The gravity disc selection for a purifier may need to be changed to match the density of the fuel. |

52

**Appendix 2** Key fuel quality characteristics and the significance of off-specification test results

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

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| **Characteristic** | **Significance** | **Implications of off-specification** |
| Sulphur | SOx emission control. Controlled to limit SOx and related particulate emissions for environmental protection.  Precursor of post-combustion low temperature corrosion of susceptible components in the engine and exhaust duct. | Statutory issue. Non-compliance with MARPOL Annex VI, Regulation 14 (and/or local controls).  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. |
| Flashpoint | The 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. The SOLAS agreement specifies that the flashpoint for all fuels used on board ships should be a minimum of 60°C, except where:   * 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 *International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels* (IGF Code).   If low flashpoint, report to Class or Flag and/or Flag Administration for guidance. |
| 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. |
| Carbon residue (DMB) | Indicator of tendency for formation of post-combustion carbon deposition; significance depends on engine design and operating profile. | 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.  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. |

53

**Appendix 2** Key fuel quality characteristics and the significance of off-specification test results

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

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| **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 *Cold flow properties* on page 16 of this guidance document. |
| Pour point | The lowest temperature at which fuel is still fluid under test conditions. | 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.  See *Cold flow properties* on page 16 of this guidance document.  This issue is addressed in greater detail in the CIMAC Guideline on *Cold flow properties of marine fuel oils* (<https://www.cimac.com/cms/upload/workinggroups/WG7/> CIMAC\_WG7\_2015\_01\_Guideline\_Cold\_\_Flow\_Properties\_Mar ine\_Fuel\_Oils\_final.pdf).  Maintain storage and handling temperatures at 10°C above the pour point to avoid risk of solidification.  Any constraints due to cold ambient conditions/winter zones should be determined. |

54 Joint Industry Guidance: The supply and use of 0.50%-sulphur marine fuel

**Appendix 2** Key fuel quality characteristics and the significance of off-specification test results

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

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| **Characteristic** | **Significance** | **Implications of off-specification** |
| Viscosity at 50°C | Ease of flow | 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).  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. |
| Density at 15°C | Weight/volume relationship of a fuel | Decrease in the density differential, which is the basis for cleaning by settling or purification/separation.  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.  Modern separators, without a conventional gravity disc can,  however, operate up to density values of around 1,010 kg/m3.  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. |
| 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. | 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.  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.  For further details and recommendations, see the CIMAC guidance document, *Fuel Quality Guide—Ignition and Combustion* (<https://www.cimac.com/publications/wg-publications/cimac-wg07-fuel-quality-guide-ignition-and-combustion.html).> |
| Sulphur | Precursor of post-  combustion low-temperature corrosion of susceptible components in the engine and exhaust duct. Controlled to limit SOx and related particulate emissions for environmental protection. | Statutory non-compliance with MARPOL Annex VI, Regulation 14 (and/or local controls).  Increased tendency to cause cold corrosion.  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. |

Joint Industry Guidance: The supply and use of 0.50%-sulphur marine fuel 55

**Appendix 2** Key fuel quality characteristics and the significance of off-specification test results

*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. |

56 Joint Industry Guidance: The supply and use of 0.50%-sulphur marine fuel

**Appendix 2** Key fuel quality characteristics and the significance of off-specification test results

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

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| --- | --- | --- |
| **Characteristic** | **Significance** | **Implications of off-specification** |
| Aluminium + | Indicator of abrasive catalytic | High levels of aluminium + silicon (catalyst fines) are not easily |
| silicon | fine material being present. | 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. |

Joint Industry Guidance: The supply and use of 0.50%-sulphur marine fuel 57