

CIMAC

**RECOMMENDATIONS
REGARDING FUEL QUALITY
FOR DIESEL ENGINES**



**The International Council
on Combustion Engines**

**Conseil International des
Machines à Combustion**



CIMAC is an international organisation, founded in 1950 by a French initiative to promote technical and scientific knowledge in the field of internal combustion engines (piston engines and gas turbines). This is achieved by the organisation of congresses and working groups.

It is supported by engine manufacturers, engine users, technical universities, research institutes, component suppliers, fuel and lubricating oil suppliers and several other interested parties.

The National Member Associations and previous CIMAC Recommendations still available are listed in the back of this publication.

This document has been elaborated by the CIMAC Working Group „Heavy Fuel“ and approved by CIMAC in June, 2003.

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Recommendations regarding Fuel Quality for Diesel Engines

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by

CIMAC HFO Working Group

SUMMARY

This fourth edition of Fuel Recommendations cancels and replaces the third edition of CIMAC Recommendations Regarding Fuel Requirements for Diesel Engines No. 11 dated 1990, which has been technically revised. These Fuel Recommendations are similar to International Standard ISO 8217 (see reference [1] Annex 11), however, in some respects the CIMAC Fuel Recommendations are more restrictive.

This fourth edition of the Fuel Recommendations introduces several important changes. Some of them are: reduction of the number of residual fuel grades from thirteen to ten; change of temperature for viscosity measurement from 100 °C to 50 °C and, therefore, revision of grade nominations; incorporation of the future lower global limits for sulphur and sulphur controlled grades for SO_x emission control areas (see reference [2] Annex 11); reduction of maximum water content to 0.5% V/V; revision of minimum viscosity limit for A 30 fuel grade; a prohibition on the inclusion of used lubricating oil in marine fuel controlled by means of inclusion of the limits for elements fingerprinting the presence of used lubricating oil.

A new sulphur content requirement may be introduced during the lifetime of this Recommendation by regional or national bodies, for example by the European Communities (see reference [3] Annex 11).

Additional information regarding some fuel characteristics is given in Annexes 1 to 11 of these Fuel Recommendations.

CIMAC assumes no legal responsibility for any consequence resulting from the application of these Fuel Recommendations.

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1. HISTORICAL BACKGROUND

The first edition of CIMAC Fuel Recommendations was published in professional magazines in January 1982. This led to further activities within the CIMAC Heavy Fuel Working Group and the preparation of the second edition of CIMAC Fuel Recommendations No 8 in 1986. In order to cope with the development of marine diesel engine designs and changes in crude oil refining processes, the third edition of CIMAC Recommendations Regarding Fuel Requirements for Diesel Engines No 11 was issued in 1990.

This fourth edition has been prepared by the members of the Heavy Fuel Working Group comprising experts from the marine engine manufacturers, marine fuel treatment plant manufacturers, refiners, fuel suppliers, additive suppliers, shipowners, research institutes and fuel testing services.

CIMAC Fuel Recommendations are being used worldwide. In 1982, when the first edition of CIMAC Fuel Recommendations was published, British Standards Institution (BSI) also prepared the first marine fuel specification BS-MA 100. This standard became the basis for the development of the first international marine fuel specification.

The demand of the marine and petroleum industries for standardisation of the marine fuel quality resulted in the introduction of the ISO 8217 standard by the International Organisation of Standardisation (ISO) in 1987. This first international standard for marine fuels was a significant technical revision of the BSMA 100:1982 standard and, therefore, replaced it.

In 1996 the second edition of ISO 8217 was published in co-operation between the marine and petroleum industries. The third, much revised Committee Draft of the ISO 8217 standard is now being prepared.

2. SCOPE

The CIMAC Fuel Recommendations cover petroleum fuels for use in marine and stationary diesel engines. The Recommendations apply to the fuel as delivered, i.e., before the appropriate treatment prior to use. These Recommendations are intended primarily for use by the engine manufacturers in their manuals. This allows the engine operators to specify fuel grades suitable for a given engine type and fuel treatment plant.

This edition of Fuel Recommendations specifies four grades of distillate fuel, one of which is for diesel engines for emergency purposes. It also specifies ten grades of residual fuel.

Requirements for gas turbine fuels used in marine applications are specified in ISO 4261.

For the purpose of this Fuel Recommendations the term 'petroleum' is used to include oil from tar sands and from shale.

The CIMAC Fuel Recommendations are published by the central CIMAC secretariat based in Frankfurt, from where all interested parties can obtain hard copies. For more information please see CIMAC web-page www.CIMAC.com.

The Fuel Recommendations will continue to be periodically reviewed and revised by the Working Group when the need arises.

3. GENERAL RECOMMENDATIONS

The fuels shall be homogeneous blends of hydrocarbons derived from petroleum refining. This shall not preclude the incorporation of small amounts of additives intended to improve some aspects of performance. The fuels shall be free from inorganic acid and from used lubricating oils.

NOTE 1: The fuel should not include any added substance or chemical waste which either:

- jeopardises the safety of ships/installations or adversely affects the performance of the machinery; or
- is harmful to personnel; or
- contributes overall to additional air pollution.

NOTE 2: Potentially harmful vapours (hydrocarbon, hydrogen sulphide, etc.) may be released from fuel oils, hence precautions should always be taken when opening valves, hatches and vent covers or when entering void spaces (see Annex 4).

The properties of the fuels are set out in tables 1 and 2.

4. SAMPLING

The sampling of petroleum fuels for analysis, for the purposes of these CIMAC Fuel Recommendations, shall be carried out in accordance with the procedures given in ISO 3170 and ISO TR/13739, clause 10, or an equivalent National Standard. Additional information on sampling procedures is given in a separate CIMAC document entitled “Background design and operation of heavy fuel treatment plants for diesel engines” (see reference [4] Annex 11).

5. NORMATIVE REFERENCES

The following test methods constitute provisions of these Fuel Recommendations. For references, which are dated, subsequent amendments to, or revisions of any of these publications do not apply. However parties to agreements based on this Fuel Recommendations are encouraged to investigate the possibility of applying the most recent editions of the test methods indicated below. For undated references the latest edition of the test methods referred to applies. Members of ISO and all national standardisation bodies maintain registers of current valid test methods.

ISO 91-1:1992, *Petroleum measurement tables — Part 1: Tables based on reference temperatures of 15 °C and 60 °F.*

ISO 2719:2002, *Determination of flash point — Pensky-Martens closed cup method.*

ISO 3015:1992, *Petroleum products — Determination of cloud point.*

ISO 3016:1994, *Petroleum products — Determination of pour point.*

ISO 3104:1994, *Petroleum products — Transparent and opaque liquids — Determination of kinematic viscosity and calculation of dynamic viscosity.*

ISO 3170:1990, *Petroleum liquids – Manual sampling*

ISO 3679: ¹⁾, *Determination of flash point – rapid equilibrium closed cup method.*

ISO 3675:1998, *Crude petroleum and liquid petroleum products — Laboratory determination of density or relative density — Hydrometer method.*

ISO 3733:1999, *Petroleum products and bituminous materials — Determination of water — Distillation method.*

ISO 4259:1992, *Petroleum products — Determination and application of precision data in relation to methods of test.*

ISO 4261:1993, *Petroleum products — Fuels (Class F)— Specifications — Gas turbine fuels for industrial and marine use.*

ISO 4264:1995, *Petroleum products — Calculation of cetane index of middle distillate fuels by the four variable equation.*

ISO 6245 ²⁾, *Petroleum products — Determination of ash.*

ISO 8216-1:1996, *Petroleum products — Fuels (class F)— Classification — Part 1: Categories of marine fuels.*

ISO 8754 ³⁾, *Petroleum products — Determination of sulfur content — Energy-dispersive X-ray fluorescence method.*

ISO 10307-1:1993, *Petroleum products — Total sediment in residual fuels — Part 1: Determination by hot filtration.*

ISO 10307-2:1993, *Petroleum products — Total sediment in residual fuels — Part 2: Standard procedures for ageing.*

ISO 10370:1993, *Petroleum products — Determination of carbon residue — Micro method.*

ISO 10478:1994, *Petroleum products — Determination of aluminium and silicon in fuel oils – Inductively coupled plasma and atomic absorption spectroscopy methods.*

ISO 12185:1996, *Crude petroleum and petroleum products — Determination of density — Oscillating u-tube method.*

ISO/TR 13739:1998, *Petroleum products – Methods for specifying practical procedures for the transfer of bunker fuels to ships.*

ISO 14596:1998, *Petroleum products – Determination of sulfur content – Wavelength Dispersive X-ray fluorescence spectrometry*

ISO 14597:1997, *Petroleum products — Determination of vanadium and nickel in liquid fuels — Wavelength Dispersive X-ray fluorescence spectrometry.*

IP 470/03, *Determination of aluminium, silicon, vanadium, nickel, iron, calcium, zinc and sodium in residual fuel oil by ashing, fusion and atomic absorption spectrometry.*
IP 500/03, *Determination of the phosphorus content of residual fuels by ultra-violet spectrometry.*

IP 501/03, *Determination of aluminium, silicon, vanadium, nickel, iron, sodium, calcium, zinc and phosphorous in residual fuel oil by ashing, fusion and inductively coupled plasma emission spectroscopy.*

¹⁾ – To be published. (Revision of ISO 3679:1983)

²⁾ – To be published. (Revision of ISO 6245:1993)

³⁾ – To be published. (Revision of ISO 8754:1992)

6. TEST METHODS

6.1 Density

When density is determined in accordance with ISO 3675, the hydrometer readings obtained at ambient temperature on distillate fuels, and at elevated temperatures of between 50 °C and 60 °C on fuels containing residual components, shall be converted to results at 15 °C using table 53B of ISO 91-1.

When density is determined in accordance with ISO 12185, an appropriate correction for glass expansion coefficient shall be applied to readings obtained by digital density analyser at any temperature other than 15 °C, before conversion and application of table 53B of ISO 91-1.

The referee method shall be ISO 3675.

6.2 Flash point

The flash point for all grades of distillate fuel listed in table 1 shall be determined in accordance with ISO 2719 Procedure A. If the flash point of a grade DX sample is less than 40 °C it shall be determined in accordance with ISO 3679.

The flash point of all grades of residual fuels listed in table 2 shall be determined in accordance with ISO 2719 Procedure B.

6.3 Sulfur content

The referee test method for compliance with these Fuel Recommendations shall be ISO 8754.

In some geographical areas, for environmental control purposes, other test methods may be specified by national authorities.

NOTE. In the event of a dispute concerning sulfur content, all parties should agree, prior to testing, to using the same sulfur certified reference material (CRM).

6.4 Appearance

For categories **DX**, **DA** and **DB**, the appearance of samples shall be assessed by visual inspection in good light, free from glare and shadow, at a temperature between 10 °C and 25 °C.

- **DX** and **DA** categories samples shall appear clear and bright.
- When the clarity of **DB** category samples affords visual inspection, and if they appear free from visible sediment and water, testing for Total Sediment Existent and for water content is not required.

6.5 Total sediment existent

The Total Sediment Existent shall be determined in accordance with ISO 10307-1 for all DB category samples that fail the visual inspection described in 6.4.

6.6 Total sediment potential

The method given in ISO 10307-2 for determination of Total Sediment Potential (Procedure A) shall be the referee method.

6.7 Used lubricating oil

The referee test method for compliance with these Fuel Recommendations shall be IP 501.

6.8 Vanadium

The referee test method for compliance with these Fuel Recommendations shall be ISO 14597.

7. PRECISION AND INTERPRETATION OF TEST RESULTS

All standard test methods specified in table 1 and 2 contain a statement of precision expressed as repeatability and reproducibility. Attention is drawn to standard ISO 4259 – “Petroleum Products: Determination and Application of Precision Data in Relation to Methods of Test”. Clauses 9 and 10 of this standard cover the use of precision data in the interpretation of the test results. This procedure shall be used in all cases of dispute.

More information about test method precision and interpretation of test results is given in Annex 9.

8. SELECTION OF FUEL GRADES

All fuel grades require appropriate fuel treatment prior to use. For more information on fuel treatment see CIMAC document entitled ‘Background design and operation of heavy fuel treatment plants for diesel engines.’

8.1 Distillate grades:

DX is a fuel, which is suitable for use at ambient temperatures down to -16°C without heating the fuel. In merchant marine applications, its use is restricted to lifeboat engines and certain emergency equipment due to reduced flash point.

DA is a high quality distillate, generally referred to as MGO (Marine Gas Oil).

DB is a general purpose fuel, which may contain trace amounts of residual fuel. It is generally referred to as distillate MDO (Marine Diesel Oil).

DC is a fuel, which can contain a significant proportion of residual component. Consequently, it is not suitable for installations where engine or fuel treatment plant is not designed for the use of residual fuels. It is generally referred to as blended MDO.

8.2 Residual grades:

A 30 is available for operation at low ambient temperatures in installations without storage tank heating, as the maximum pour point temperature is zero. **B 30** may require some storage tank heating, as the fuel may not flow at temperatures below +24 °C. Of these two grades, **A 30** has a lower maximum density limit and a minimum viscosity limit to increase the probability of good ignition properties.

D 80 up to H 700 are fuel blends that require treatment before use by a conventional purifier-clarifier centrifuge (separator) system, in order to reduce the content of contaminants to an acceptable level. Generally for engine operation the highest viscosity (taking into account the maximum pre-heat temperature allowed by the engine design) should be used, except when other parameters take precedence over viscosity in selecting the fuel grade.

K 380 and K 700 are only for use in installations with centrifuges (separators) specially designed for higher density fuels (above 991 kg/m³).

Table 1: Recommendations for distillate fuels for diesel engines (as bunkered)

	CIMAC Designation	DX	DA	DB	DC ¹⁾	Test method reference
Characteristics	Unit	Limit				
Density at 15 °C	Kg/m ³	-	890.0	900.0	920.0	ISO 3675 or ISO 12185 (see 6.1)
Kinematic viscosity at 40°C	mm ² /s ²⁾	5.50	6.00	11.0	14.0	ISO 3104
		1.40	1.50	2.50	4.00	ISO 3104
Flash point	min	43	60	60	60	ISO 2719 (see also 6.2)
	max	-	-6	0	0	ISO 3016
Pour point	winter quality	-	0	6	6	ISO 3016
	summer quality	-	-	-	-	ISO 3015
Cloud point	°C ³⁾	-16 ³⁾	-	-	-	ISO 10370
Carbon residue	10% (V/V) Distillation bottoms	0.30	0.30	-	-	ISO 10370
	Carbon residue	-	-	0.30	2.5	ISO 10370
Ash	% (m/m)	0.01	0.01	0.01	0.03	ISO 6245
	% (m/m)	Clear & Bright	-	-	-	(see also 6.4 and 6.5)
Appearance ⁴⁾						
Total sediment existent	% (m/m)	-	-	0.10	0.10	ISO 10307-1 (see also 6.5)
Water	% (V/V)	-	-	0.3	0.3	ISO 3733
	min	45	40	35	35	ISO 4264
Cetane Index						
Sulphur ⁵⁾	% (m/m)	1.00	1.50	2.00 ⁵⁾	2.00 ⁵⁾	ISO 8754 or ISO 14596 (see also 6.3)
	mg/kg	-	-	-	100	ISO 14597 or IP 501 (see also 6.8)
Vanadium	mg/kg	-	-	-	25	ISO 10478
Aluminium + Silicon	mg/kg	-	-	-	-	
Used lubricating oil (ULO)					The fuel shall be free of ULO (see Table 2)	
	Zinc	mg/kg			15	IP 501 or IP 470
	Phosphorus	mg/kg			15	IP 501 or IP 500
	Calcium	mg/kg			30	IP 501 or IP 470 (see also 6.7)

1) Note that although predominantly consisting of distillate fuel, the residual oil proportion can be significant.

2) 1 mm²/s = 1 cSt

3) This fuel is suitable for use without heating at ambient temperature down to – 16°C

4) If the sample is clear and with no visible sediment and water, the total sediment existent and water test shall not be required.

5) A sulphur limit of 1.5% m/m will apply in SOx Emission Control Areas designated by the IMO, when its relevant Protocol comes into force. There may be local variations.

Table 2: Recommendations for residual fuels for diesel engines (as bunkered)

Characteristics ¹⁾	Unit	Limit	CIMAC A 30	CIMAC B 30	CIMAC D 80	CIMAC E 180	CIMAC F 180	CIMAC G 380	CIMAC H 380	CIMAC K 380	CIMAC H 700	CIMAC K 700	Test method reference
Density at 15 °C,	kg/m ³	max.	960,0	975,0	980,0	991,0	991,0	991,0	991,0	1010,0	991,0	1010,0	ISO 3675 or ISO 12185 (see also 6.1)
Kinematic viscosity at 50 °C	mm ² /s ²⁾	max.	30,0		80,0	180,0		380,0			700,0		ISO 3104
		min. ³⁾	22,0		-	-		-			-		ISO 3104
Flash point,	°C	min.	60	60	60	60	60	60	60	60	60	60	ISO 2719 (see also 6.2)
Pour point (upper) - winter quality - summer quality	°C	max.	0	24	30	30	30	30	30	30	30	30	ISO 3016
		max.	6	24	30	30	30	30	30	30	30	30	ISO 3016
Carbon residue	% (m/m)	max.	10		14	15	20	18		22			ISO 10370
Ash	% (m/m)	max.	0,10		0,10	0,10	0,15		0,15				ISO 6245
Water	% (V/V)	max.	0,5		0,5	0,5			0,5				ISO 3733
Sulfur ⁴⁾	% (m/m)	max.	3,50		4,00	4,50	4,50		4,50				ISO 14596 or ISO 8754 (see also 6.3)
Vanadium	mg/kg	max.	150		350	200	500	300		600			ISO 14597 or IP 501 (see also 6.8)
Total sediment potential	% (m/m)	max.	0,10		0,10	0,10	0,10		0,10				ISO 10307-2 (see also 6.6)
Aluminium plus silicon ⁵⁾	mg/kg	max.	80		80	80	80		80				ISO 10478
Used lubricating oil (ULO)			The fuel shall be free of ULO. A fuel shall be considered to be free of ULO if one or more of the elements Zinc, Phosphorus and Calcium are below or at the specified limits. <u>All</u> three elements must exceed the same limits before a fuel shall be deemed to contain ULO.										
Zinc	mg/kg	-											IP 501 or IP 470
Phosphorus	mg/kg	-											IP 501 or IP 500
Calcium	mg/kg	-											IP 501 or IP 470 (see also 6.7)

1) See General Recommendations paragraph 3 for additional characteristics not included in this table

2) 1 mm²/s = 1 cSt

3) Fuels with density close to the *maximum*, but with very low viscosity, may exhibit poor ignition quality. See Annex 6.

4) A sulphur limit of 1.5% m/m will apply in SOx Emission Control Areas designated by the IMO, when its relevant Protocol comes into force. There may be local variations.

5) See Annex 3.



Annex 1

SPECIFIC ENERGY

1.1 Specific energy is not controlled in the manufacture of fuel except in a secondary manner by the presence and concentration of other properties.

1.2 For residual fuels, net specific energy, N_a , and gross specific energy, G , both in megajoules per kilogram, can be calculated with a degree of accuracy acceptable for normal purposes from the equations given below. (see also reference [8] in annex 11).

$$N_a = (46,704 - 8,802\rho_{15}^2 10^{-6} + 3,167\rho_{15} 10^{-3}) \times [1 - 0,01(w+a+s)] + 0,0942s - 0,024w$$

$$G = (52,190 - 8,802\rho_{15}^2 10^{-6}) \times [1 - 0,01(w+a+s)] + 0,0942s$$

where

ρ_{15} is the density at 15 °C, in kilograms per cubic metre
 w is the water content, expressed as a percentage by mass
 a is the ash content, expressed as a percentage by mass
 s is the sulphur content, expressed as a percentage by mass

1.3 Alternatively, for the purposes of rapid estimation, the net specific energy of marine residual fuels may be conveniently read off from figure 1.1, which has been derived from the equation given in clause 1.2. However, the value obtained may be only approximate.

1.4 For marine distillate fuels, net specific energy, N_a , in megajoules per kilogram, can be calculated with a degree of accuracy acceptable for normal purposes from the equation given below.

$$N_a = (46,423 - 8,792\rho_{15}^2 10^{-6} + 3,17\rho_{15} 10^{-3}) \times [1 - 0,01(w + a + s)] + 0,0942s - 0,024w$$

where

ρ_{15} is the density at 15 °C, in kilograms per cubic metre
 w is the water content, expressed as a percentage by mass
 a is the ash content, expressed as a percentage by mass
 s is the sulphur content, expressed as a percentage by mass

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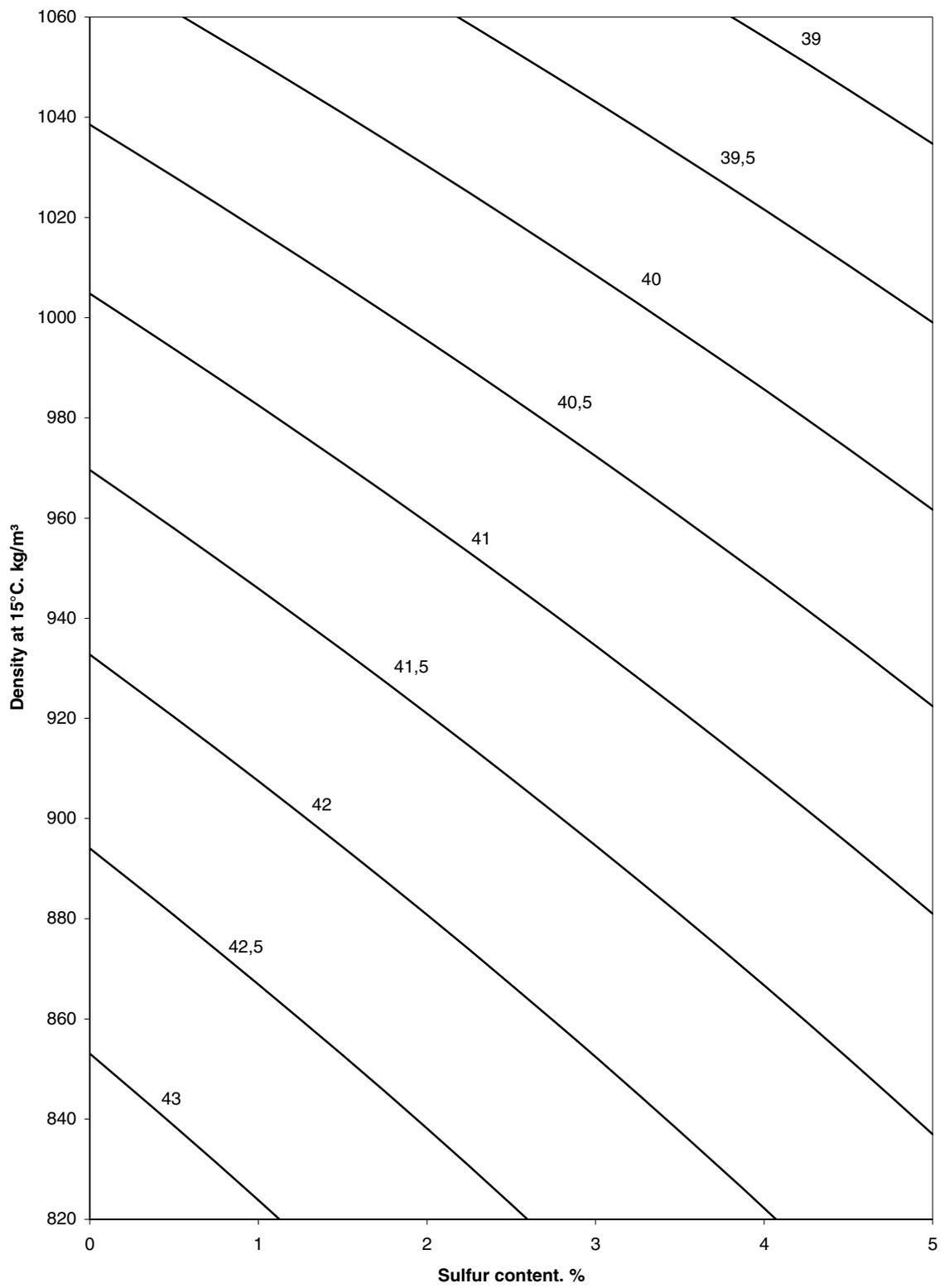


Figure 1 — Net specific energy, in megajoules per kilogram, of marine residual fuels.

Annex 2

TOTAL SEDIMENT TEST METHOD

All residual fuels contain a certain amount of sediment. This sediment can be both of organic and inorganic nature. The total sediment is defined as the sum of the insoluble organic and inorganic material which is separated from the bulk of the sample by filtration through a specified filter and which is also insoluble in a predominantly paraffinic solvent. The Total Sediment test assesses both the cleanliness and stability of the fuel without differentiating between these two properties. Fuels with Total Sediment content in excess of the specification limit can cause severe difficulties in use.

Total Sediment content is a function of the following three different fuel properties:

Cleanliness

This term refers to inorganic adventitious matter such as sand, dust, particles of rust, dirt, catalyst fines, other solid/inorganic contaminants and free carbon. All of these are filterable sediments and will be separated from the fuel sample during laboratory filtration through the glass-fibre filter with a nominal porosity of 0.0016 mm.

Stability

The stability of a fuel oil can be described as the resistance of a fuel oil to break down and precipitate asphaltenes in the form of sludge. Naturally occurring asphaltenes are characteristics of all crude oils to a greater or lesser extent. In a stable fuel oil, asphaltenes are held in suspension in the bulk of the fuel oil by forces created by the naturally existing balance between the chemical composition of the fuel matrix (available aromaticity) and the asphaltene molecules. All straight run fuel oils are stable, because the fuel will contain sufficient aromaticity to hold the asphaltenes in suspension or dispersion throughout the fuel phase.

During secondary refining the stability reserve may be reduced which may create instability. This can be measured by the Total Sediment test Part 1 entitled "Determination by Hot Filtration" - test method ISO 10307-1. This test is often referred to as Total Sediment Existent.

The imbalance between asphaltenes and available aromaticity may also create a reduction in the stability reserve of the fuel. The stability reserve gives some latitude in the dilution and heat treatment that a fuel may absorb without any sludge precipitation. Reduced stability reserve means that even small changes in external conditions will bring about instability. The stability reserve can be assessed by Total Sediment Accelerated (chemical ageing of a fuel by the use of chemical solvent and 1 hour heating at 100 deg C) and Total Sediment Potential (thermal ageing of a fuel by heating the fuel for 24 hours at 100 deg C). These two ageing procedures are covered by Total Sediment test Part 2 entitled "Determination using standard procedures for ageing" - test method ISO 10307-2. CIMAC Fuel Recommendations limit Total Sediment Potential by ISO 10307-2 for residual fuel oils and Total Sediment Determination by Hot Filtration by ISO 10307-1 for DB and DC grade fuel oil grades.

Compatibility

By definition, compatibility is the ability of two or more fuels to exist in close and permanent association for an indefinite period of time. Compatible fuels are miscible in all proportions with each other and do not cause precipitation of sludge. Incompatibility therefore is the tendency of the fuel oil to produce a deposit when blended with other fuel or fuels. Two fuels, each stable within themselves, may prove to be incompatible when mixed. The mechanism of incompatibility is similar to that of stability and depends on the chemistry of the blended fuels. The precipitated sludge consists of asphaltenes. The formation of sludge can have serious consequences and cause operational problems. The risk of incompatibility should therefore be avoided as much as possible by the appropriate design and operation of the fuel storage and treatment installation (see reference [4] Annex 11 - CIMAC document entitled "Background design and operation of heavy fuel treatment plants for diesel engines"). Commingling different fuels in shipboard storage tanks should be avoided, if possible.

For field use, ASTM D4740 spot test can be carried out to provide a quick assessment of whether two or more fuels are compatible with each other. However, experience has shown that occasionally compatible fuels failed to pass this test due to the deficiencies of the test procedure.

An indication of the compatibility of two or more fuels can be obtained by using Total Sediment test ISO 10307-1 and applying it to a mixture of the fuels in the intended ratio. However, since compatibility is not a property of the delivered fuel alone, it cannot be included in these recommendations.

Annex 3

CATALYST FINES

The main source of potentially abrasive particulates in bunker fuels is catalyst fines. The selected control parameter, aluminium plus silicon, with limit values for all fuels in table 2 and category DC in table 1, is intended to limit catalyst fines contamination to a level that will ensure minimal risk of abrasive wear, given that adequate fuel pre-treatment is achieved.

There are significant variations from refinery to refinery in the proportions of the aluminium and the silicon compounds that comprise catalyst fines. The combined aluminium and silicon limit is intended, therefore, to reflect such variations. With the impact of these fines upon engines, consideration will be given in future Recommendations to reduce this limit.

The lower limit for aluminium plus silicon applied to category DC of 25 mg/kg is based on the proportion of residual fuel that may be expected to be part of this fuel grade.

A deficiency of this approach is that the engine wear rate also may be related to the particle size distribution and to the hardness of the particles. However, these characteristics cannot readily be controlled by a fuel specification.

The effectiveness of the fuel treatment is of paramount importance and the selected limit is based on the presumption that the fuel treatment system is designed to optimum standards and operated under optimum conditions.

For additional information on fuel treatment systems see CIMAC document entitled "Background design and operation of heavy fuel treatment plants for diesel engines" (see reference [4] annex 11).

Annex 4

FLASH POINT - RESIDUAL FUEL OILS

Whilst flash point is a valid indicator of the fire hazard posed by residual fuel oil, information is available which shows that it is not a reliable indicator of the flammability conditions that can exist within the headspaces of tanks containing such fuel oils. This means that residual fuel oil can have the potential to produce a flammable atmosphere in the tank headspace, even when stored at a temperature below the measured flash point.

Consequently residual fuel oils should be considered to be potentially hazardous and capable of producing light hydrocarbons which could result in tank headspace atmospheres being near to, or within, the flammable range. Appropriate precautions are necessary therefore to ensure the safety of people and property. Further information and advice on precautionary measures are given in references [5], [6] and [7] in Annex 11.

Annex 5

VISCOSITY CONVERSIONS

These Fuel Recommendations specify limiting values of kinematic viscosity at 50 °C for the fuel categories contained in table 2. In some cases kinematic viscosity may be measured or quoted at other temperatures, and table 5.1 below gives approximate relationships. The data should be used with caution because the variability of composition of residual fuels may cause variations in viscosity-temperature relationships.

Table 5.1 — Viscosities estimated from those measured at 50 °C

Kinematic viscosity, mm ² /s ¹⁾				
Measured at 50 °C	Approximate estimations at:-			
	40 °C	100 °C	125 °C	150 °C
30	45	7	4	3
80	135	13	7	4
180	330	22	11	7
380	750	35	16	9
700	1500	50	22	11

¹⁾ 1 mm²/s = 1 cSt.

Annex 6

IGNITION PROPERTIES

6.1 Calculated Carbon Aromaticity Index - CCAI

Ignition performance requirements of residual fuels in marine diesel engines are primarily determined by engine type and, more significantly, by engine operating conditions. No standard test method for determination of the ignition quality of residual fuels is currently available.

Published work, however, has shown an empirical relationship between the density, the viscosity and the ignition performance of a fuel. Based on experimental work it was concluded that ignition quality can be related to fuel aromaticity, which for this purpose can be defined as the percentage of a fuel's carbon atoms that are located in dense aromatic structures.

Aromatic molecules increase ignition delay because they have a relatively high thermal stability in the gas phase. A longer ignition delay gives a greater risk of ignition trouble, although this also depends on the magnitude and the rate of pressure rise after ignition.

However, the measurement of aromaticity is not straightforward. Hence a correlation has been established between carbon-aromaticity and the density and viscosity of the fuel, as it was observed that fuels causing ignition problems often (not always) have a higher density than normally found at the given viscosity. The Calculated Carbon Aromaticity Index (CCAI), developed by Shell, is an indication of carbon-aromaticity, which allows ranking of fuel ignition performance. The CCAI value can be calculated using the following formulae:

$$CCAI = p - 81 - 141 \lg [\lg (v + 0.85)] - 483 \lg \left(\frac{T + 273}{323} \right)$$

where

- T* is the temperature, in degrees Celsius, at which the kinematic viscosity is determined
v is the kinematic viscosity, in millimetres squared per second
p is the density at 15°C, in kilograms per cubic metre

CCAI values can also be obtained by drawing a straight line through the determined viscosity and density values of a fuel oil in the nomogram and extending the line to the CCAI scale.

Several engine manufacturers have published their experiences with ignition quality for various engine types by referring to desired CCAI values of the fuels used. For a large group of engines CCAI value in the range of 870-890 indicates increased probability of ignition problems. For engines using lower viscosity fuel grades, up to about 180 cSt at 50°C, the CCAI value can range between 840 and 870 but it is preferable to be below 840.

However it has now become clear that the density-viscosity relation does not always allow a good prediction of ignition quality, especially when considering low viscosity and high density fuels.

The table below shows the only fuel grade that has a limit on minimum viscosity, which is due to its probable use in older, more sensitive engine types. This grade is shown here together with the calculated maximum CCAI value:

Fuel grade	A 30
density (kg/m ³) at 15° C, max.	950
viscosity (mm ² /s) at 50°C, max	30
viscosity (mm ² /s) at 50°C, min.	22
CCAI, max.	850

The viscosity may be lower than the minimum value specified above if the density is sufficiently low, which will still ensure that the specified maximum CCAI value is not exceeded.

The CCAI value required for a certain engine type and application is normally specified by the engine manufacturer or may be obtained by experience. The graphs on following pages have been added to enable the user to plot the CCAI values of fuels that give, or do not give, ignition difficulties and thus derive the statistically acceptable CCAI value for a particular operation.

6.2 Constant volume combustion instruments.

So far a standardised test method for the determination of ignition and combustion quality of residual fuels has not been established. However a test instrument utilising a constant volume combustion technology has been developed and is currently being used for marine fuel testing at a number of fuel testing laboratories and marine diesel engine manufacturers world-wide.

The ignition quality of a fuel is determined as an Ignition Delay and time delay for Start of Main Combustion (both in milliseconds). By use of calibration fuels the recorded Ignition Delay can be converted into an instrument related Cetane Number. In addition the Rate of Heat Release (ROHR) is determined, reflecting the actual heat release process and thus the combustion characteristics of the fuel tested.

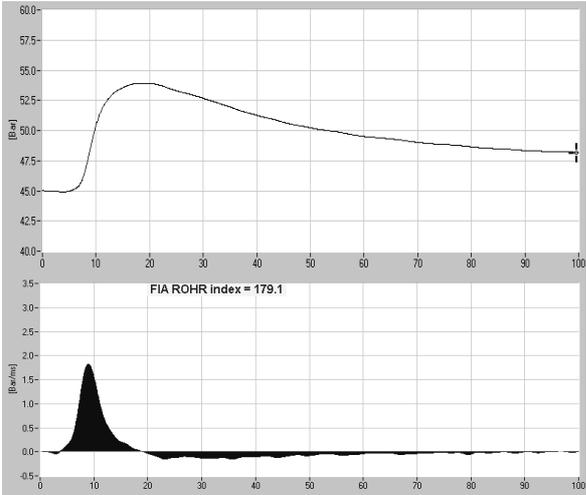
The test results appear to reflect the differences in ignition and combustion properties of marine fuels due to variations in their chemical composition.

At the present time a large number of heavy fuels are being tested for the purpose of relating the results obtained from the instruments to the fuel ignition performance as well as correlating the results with engine performance.

In co-operation with engine manufacturers, fuel testing laboratories and users of marine heavy fuel, typical limits for satisfactory fuel ignition and combustion quality at which operational disturbances are not encountered, are being established. These limits will vary depending on engine type, engine load level, operational modes and other parameters.

The two diagrams below present typical test results (Pressure Trace and Rate of Heat Release as observed in the instrument) for a normal heavy fuel oil with good ignition quality and for comparison, the test results for a problem heavy fuel oil with very bad ignition and combustion properties. For more information see reference [9], [10] and [11] in Annex 11.

Normal heavy fuel oil



Problem heavy fuel oil

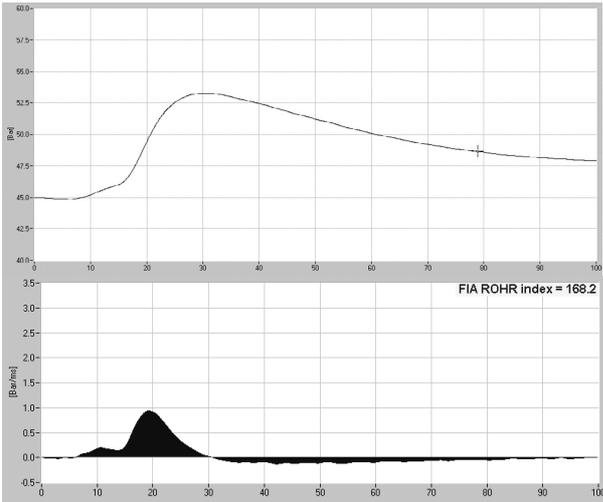


Fig. 1: Typical test results for a normal and a problem heavy fuel oil.

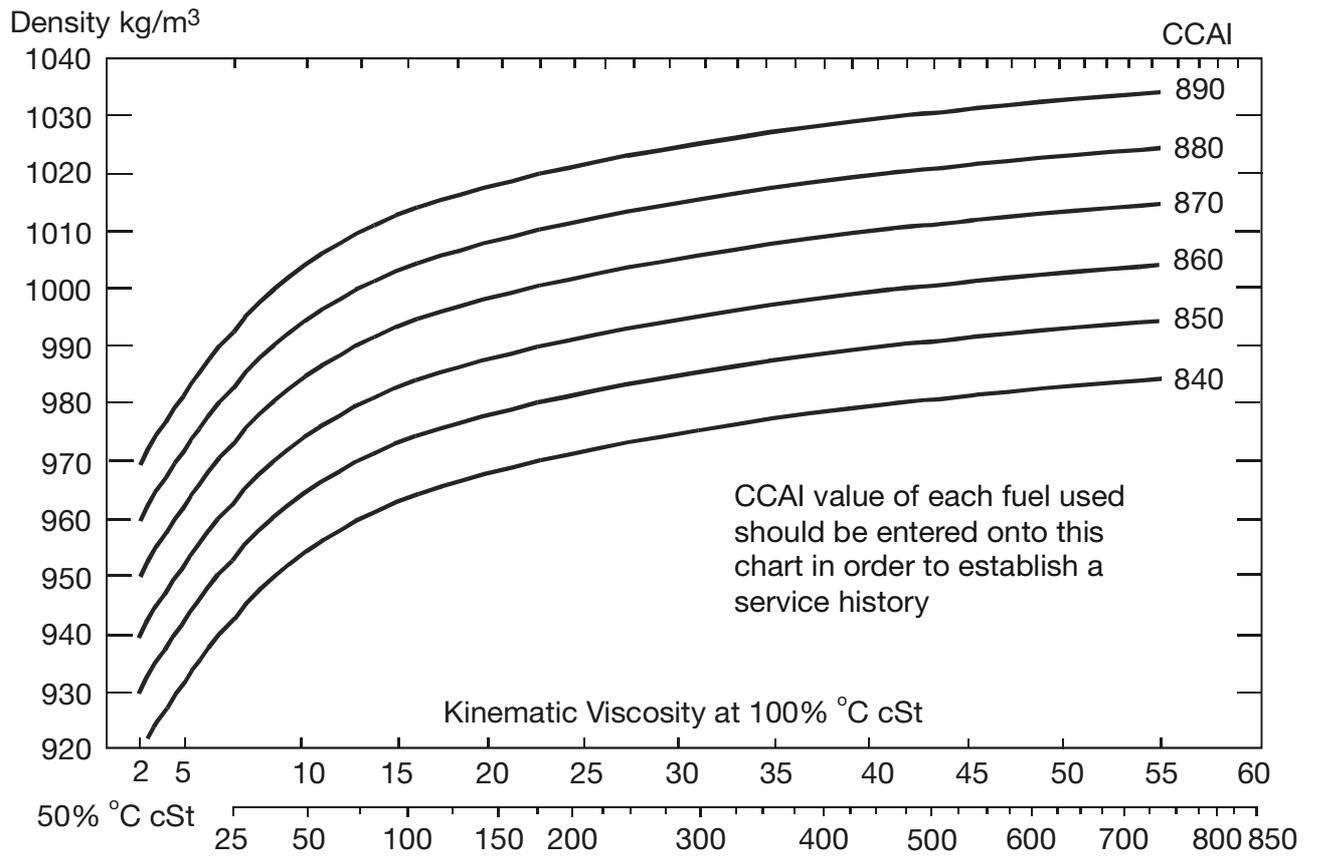


Fig. 2: CCAI service experience.

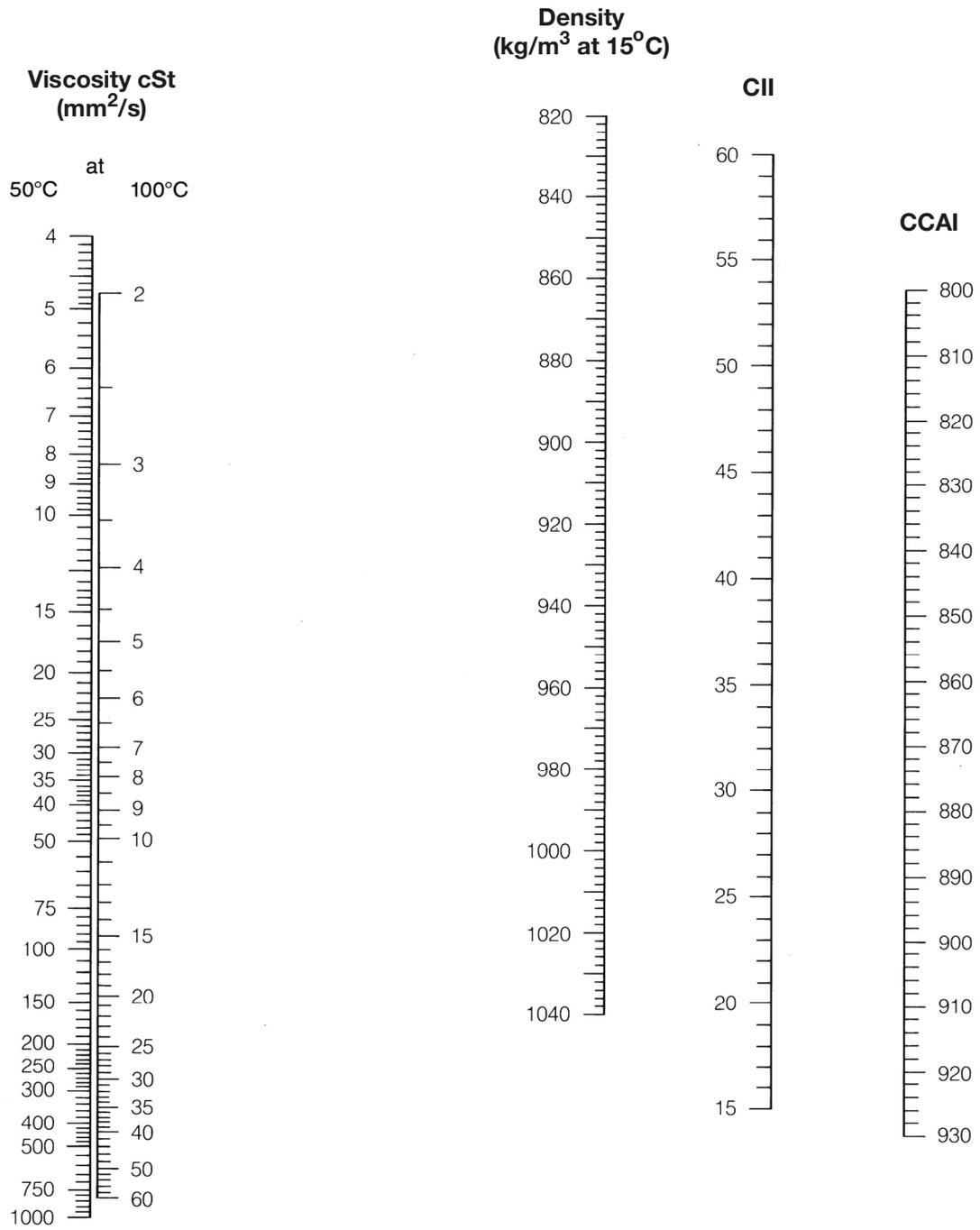


Fig. 3: Nomogram for deriving CCAI

Annex 7

VANADIUM AND SODIUM IN RESIDUAL FUELS

7.1 Introduction

All residual fuels contain some metallic elements, either those which are naturally present such as vanadium [V], or those introduced from external sources such as sodium [Na] from sea water, aluminium and silicon [Al & Si] from catalyst fines and iron [Fe] from rust. When a fuel is burned some of these metals are converted into solid particles of oxides, sulphates or more complex compounds, collectively known as ash. The nature of these compounds is such that at certain higher temperatures these solid ash particles will become partly fluid. In this state they can adhere to the engine components in a combustion system, when the component surface temperatures are high enough. These adhering ash deposits can cause damage to components (piston crowns, exhaust valves and turbocharger blade surfaces), either by a process termed 'hot corrosion' or by other mechanisms. The temperature at which the ash particles start to become fluid and to stick to surfaces, often referred to as the 'stiction' temperature, is lowest for ashes which are rich in V and Na. It is for this reason that particular attention is paid to the amounts of these metals in fuels.

7.2 Ash melting points

Melting points of ashes vary greatly depending on ash constituents. For example sodium vanadyl vanadate, as an uncontaminated compound, has an ash melting temperature of 535 °C. However this can be depressed further by solution of other metal oxides derived from corroding surfaces. For this reason ash melting temperatures well below 400 °C are theoretically possible. A sodium/vanadium ratio of 1:3 is frequently claimed to yield the lowest ash melting temperature. This is correct for a simple two component ($\text{Na}_2\text{SO}_4/\text{V}_2\text{O}_5$) ash complex. Ashes derived from combustion of residual fuel oils are, however, complex mixture of compounds which will also incorporate calcium, nickel, silicon and aluminium, together with many other metals at lower concentrations. All of these additional metals will tend to influence ash melting temperatures, in some cases exerting a beneficial effect by making the ash less prone to adhering to surfaces, while in other cases having the opposite effect.

The critical 1:3 Na/V ratio assumes increasing importance as the vanadium content of the fuel oil rises because the ash will become increasingly vanadium rich. While vanadium levels in a residual fuel can be several hundreds of mg/kg, other metals do not usually reach such levels; therefore their influence on 'stiction' temperatures is reduced. Also, at high vanadium levels the total ash burden will be greater, thus exacerbating any problems, which may arise due to ash deposition.

It is not uncommon to find that some operator's specifications limit the maximum sodium level to one-third of the vanadium level. Clearly such a generalised limit is not well founded scientifically and is unnecessarily restrictive, particularly at lower vanadium levels say at levels lower than 150 mg/kg.

7.3 Vanadium and sodium levels

Vanadium is a natural component of every crude oil and therefore every fuel oil produced. It is not present as a single neat element, but it exists in the fuel oil within the complex hydrocarbon molecules containing both vanadium and other elements. These large molecules are effectively dissolved within the fuel oil phase. There are no practical methods by which vanadium can be removed from fuel oil on board ship. Therefore, the only practical way to restrict vanadium is by limiting its content in the fuel purchasing arrangements. What

constitutes a realistic limit will be dependent primarily on operational experience and the known sensitivity of the particular engine or boiler to ash related problems, as well as on the availability and price of the preferred fuel oil quality at the bunkering ports.

The level of sodium that may be present in bunker fuel is not directly controlled in Fuel Recommendations. The reason for this is that the usual source of sodium is seawater contamination. Each one percent of sea water, on average, contains about 100 mg/kg of sodium, while fuels that are essentially water free will normally have sodium contents between about 1 and 50 mg/kg, rarely any significantly higher. The sodium can also enter the combustion zone in a form of sea water aerosol entrained in the charging air, particularly during rough weather conditions.

Unlike vanadium, sodium is not usually present in the fuel in an oil soluble form. In most cases high sodium levels are associated with sea water contamination, hence the amount of sodium removed will be directly proportional to the amount of water that can be removed in settling tanks and by centrifugal treatment of the fuel. Very occasionally sodium hydroxide used in the refining process may be the source of sodium contamination. Some of this sodium may also be present in an oil soluble form that cannot be removed, but the level is normally low and down to few mg/kg.

Experience from CIMAC Users WG suggests the following precautions in order to avoid performance reductions of diesel engines:

- Avoid fuel oils with vanadium content above 150 mg/kg
- Avoid fuels oils with “dry” sodium content
- Avoid exhaust gas temperatures above 550 °C before turbocharger in order to minimise deposits of sodium-vanadium salts on turbocharger nozzle ring or turbine. Alternatively appropriate fuel oil additive can be used to increase the ash melting point temperature.
- Minimise the water content in the charging air by installation of an effective de-mister after the scavenging air cooler.
- Ensure that free saltwater in the fuel is removed by fuel treatment.

7.4 Engineering solutions to the problem

The engineering solution to the prevention of hot corrosion is primarily achieved by a combination of control of metal surface temperature and selection of alloys that have the physical properties capable of resisting hot corrosion. Nimonic 80A and Nimonic 81 alloys are regarded by many to represent the ‘industry standard’ materials for best performance of exhaust valves.

There have also been significant advances in engine design in recent years, which have aimed to prevent the ash adhesion to the critical engine components. Examples of this are more efficient cooling of valve seats and faces, and the use of valve rotators to even out the thermal load on valves. As a result of all the advances, modern engine designs are much more tolerant to vanadium and sodium than earlier designs. Manufacturers’ recommendations for acceptable vanadium levels span a wide range up to 600 mg/kg of vanadium for more modern engine designs.

Annex 8

ACIDITY IN FUELS

Fuels with high acid numbers arising from acidic compounds occasionally have caused accelerated damage to marine diesel engines. Such damages have been found primarily within the fuel injectors and associated pumps. These failures have resulted shortly after commencement of use of the bunker supplies.

Analysing fuels for Acid Number (AN) by using ISO 6619 test method entitled '*Petroleum products – Neutralization number – Potentiometric titration method*', can give indications as to the likely presence of acidic compounds. Although many fuels have a measurable acid number, The AN levels are generally (but not always) below 3 mg KOH/g and values above this might indicate significant amounts of acidic compounds and, possibly, other contaminants. However an AN below 3 mg KOH/g does not guarantee that the fuel would be free from problems associated with the presence of acidic compounds.

In spite of the availability of significant analytical data, there is no currently recognised correlation between AN test method results and the corrosive activity of a fuel.

Annex 9

EXAMPLES OF PRECISION AND INTERPRETATION OF TEST RESULTS

9.1 Introduction

Marine fuel quality complaints can be categorised generally as either those where a problem has occurred on board or where there is a dispute over the acceptability of the product prior to its use. Whichever the case, the fuel must be tested to ascertain its nature.

9.2 Use of ISO 4259

Tables 1 and 2 of these Fuel Recommendations specify maximum and minimum limits to the *true value* of a given property. *True value*, as defined by ISO 4259:1992, represents the average of an infinite number of single results obtained by an infinite number of laboratories. Therefore this true value can never be established exactly. A fuel test, run a number of times at the same laboratory, by the same person, on the same sample, under the same conditions, will rarely yield exactly the same answer for each test run. Occasional human mistakes or omissions will introduce a random error, which can be quantified for each test method as *Repeatability* (*r*). When two different laboratories test the same sample using the same method, the random error is called *Reproducibility* (*R*).

Clause 7.1 of this Standard states:

‘The test methods specified in clause 6 all contain a statement of precision (repeatability and reproducibility). Attention is drawn to ISO 4259:1992, clauses 9 and 10, which cover the use of precision data in the interpretation of test results, and this method shall be used in cases of dispute.’

Clause 9 of ISO 4259, *Quality control against specifications*, provides information to allow the supplier or the recipient of fuels to judge the quality of a product with regard to the specification when a single result is available.

9.3 Recipient with a single test result

A recipient who has no other information on the true value of a characteristic, other than a single test result, can consider that the product fails the specification limit, with 95 % confidence, only if the test result is such that

in the case of a maximum specification limit -

test result > specification limit + 0,59 x Reproducibility

or in the case of a minimum specification limit -

test result < specification limit - 0,59 x Reproducibility

Example:

Recipient has ordered fuel to CIMAC G 380 specification in which the limit on viscosity is 380 mm²/s @ 50 °C max.

For the test method, ISO 3104, *Determination of kinematic viscosity ...*, when the viscosity is measured at 50 °C, R is 0,074x, or 7,4% of the test value.

Therefore, at 380 mm²/s @ 50 °C, R = 0,074 x 380 = 28,12 mm²/s @ 50 °C.

Consequently, if the single test result is > 380 + (0,59 x 28,12) = > 396,59 then the recipient can consider the sample to fail the specification with 95% confidence.

9.4 Supplier with a single test result

Similarly, a supplier who has no other source of information than a single result shall consider that the fuel meets the specification limit, with 95 % confidence, only if the test result is such that

in the case of a maximum specification limit -

test result ≤ specification limit - 0,59 x Reproducibility

or in the case of a minimum specification limit -

test result ≥ specification limit + 0,59 x Reproducibility

Example:

Supplier has delivered fuel to the CIMAC G 380 specification in which the limit on viscosity is 380 mm²/s @ 50 °C max.

For the test method ISO 3104, *Determination of kinematic viscosity ...*, when the viscosity is measured at 50 °C, R is 0,074x, or 7,4% of the test value.

Therefore, at 380 mm²/s @ 50 °C, R = 0,074 x 380 = 28,12 mm²/s @ 50 °C

Consequently if a single test result is < 380 - (0,59 x 28,12) = < 363,14 then the supplier can consider the sample to meet the specification with 95% confidence.

9.5 Resolving disputes

If it is not possible for the supplier and the recipient to reach agreement about the quality of the product, procedures given in Clause 10 of ISO 4259, *Acceptance and rejection rules in case of dispute*, should be followed.

The reader should refer to the full text of ISO 4259 for a definitive procedure.

Annex 10

USED LUBRICATING OILS (ULO) IN FUELS

Used lubricating oils (ULO) have been added to bunker fuels in some parts of the world for over 25 years. The acceptability of this practice has become a highly contentious issue, however, even in areas where it is officially encouraged and where strict environmental rules exist.

While the presence of ULO may elicit images of diverse industrial residues or wastes being disposed of in the fuel, in truth, this is uncommonly rare, as such oils have generally been comprised of predominantly spent motor vehicle crankcase oils.

Although the proportion of fuels containing ULO varies, best estimates are that its presence has varied up to 3% of fuel samples tested.

The technical and commercial opinion on the subject is very strongly divided

The arguments presented for allowing Used Lubricating Oil (ULO) in bunker fuels include:

- there is no firm or conclusive evidence of any harmful effects of ULO, at least at “low” levels (although the definition of “low” is imprecise)
- many shipowners adopt the practice of disposing of a ship’s own used crankcase oils to the ship’s fuel, and therefore the disposal of ULO from land-based sources is thought to be equally acceptable
- field studies of the efficiency of shipboard fuel treatment have not shown any significant adverse effect when ULO is present

The arguments presented for opposing the practice include:

- various laboratory studies of centrifuge performance have been carried out, and some of these (but not all) indicate that ULO can have an adverse effect on centrifuge performance
- ULO addition may lead to engine problems such as accelerated turbocharger fouling (due to increased ash loading), or fuel pump damage (due to increased abrasives and/or cavitation damage due to water)
- the addition of ULO as a fuel blend component collected from inland sources with no or inadequate environmental regulations may provide a route for other waste materials (e.g. industrial solvents) to enter the bunker fuel oil pool

In addition to these technical considerations, there is also a commercial view that users and purchasers are unhappy at paying fuel oil prices for what they perceive to be someone else’s waste products.

As a consequence many purchasers now include a clause specifying that the fuel “shall contain no ULO”. However, such a clause is too loosely defined to enable monitoring of the requirement. For this reason Fuel Recommendations now contain limits on appropriate “fingerprint” elements of ULO. These limits are designed to prevent, as far as possible, any addition of ULO to marine fuels, as explained below.

Potentially ULO is quite a variable material but, as noted above, is comprised predominantly of used vehicle crankcase oils. Such oils contain significant amounts of detergent and anti-wear additives. Detergent additives are based mainly on calcium, while anti-wear additives are usually zinc-phosphorous compounds. However it is not possible to set a zero upper limit on these “fingerprint” elements because the same elements can originate from natural sources. The levels are usually only a few mg/kg, but for fuel oil derived from some crude oils, the levels of these elements can be very much higher.

The principle used in setting limits for this standard is that if ULO is present then all three of the “fingerprint” elements will also be present in significant amounts. Natural sources of the elements, on the other hand, are expected to show a high concentration for only one of the elements. Limits for the selected elements of zinc, phosphorous and calcium have been set at levels that are as low as possible, taking into account both the background levels of these elements in fuels free of ULO, and the reproducibility of the test methods.

The limits on zinc, phosphorous and calcium given in Tables 1 and 2 serve as the basis for determining whether or not a fuel meets the specification, but do not imply that a fuel which is judged to contain ULO is *necessarily* unsuitable for use. As with all specification parameters, the appropriate action in the event of a deviation from specification must take into account the specific circumstances of the case.

For more information see reference [12] in annex 11.

Annex 11

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