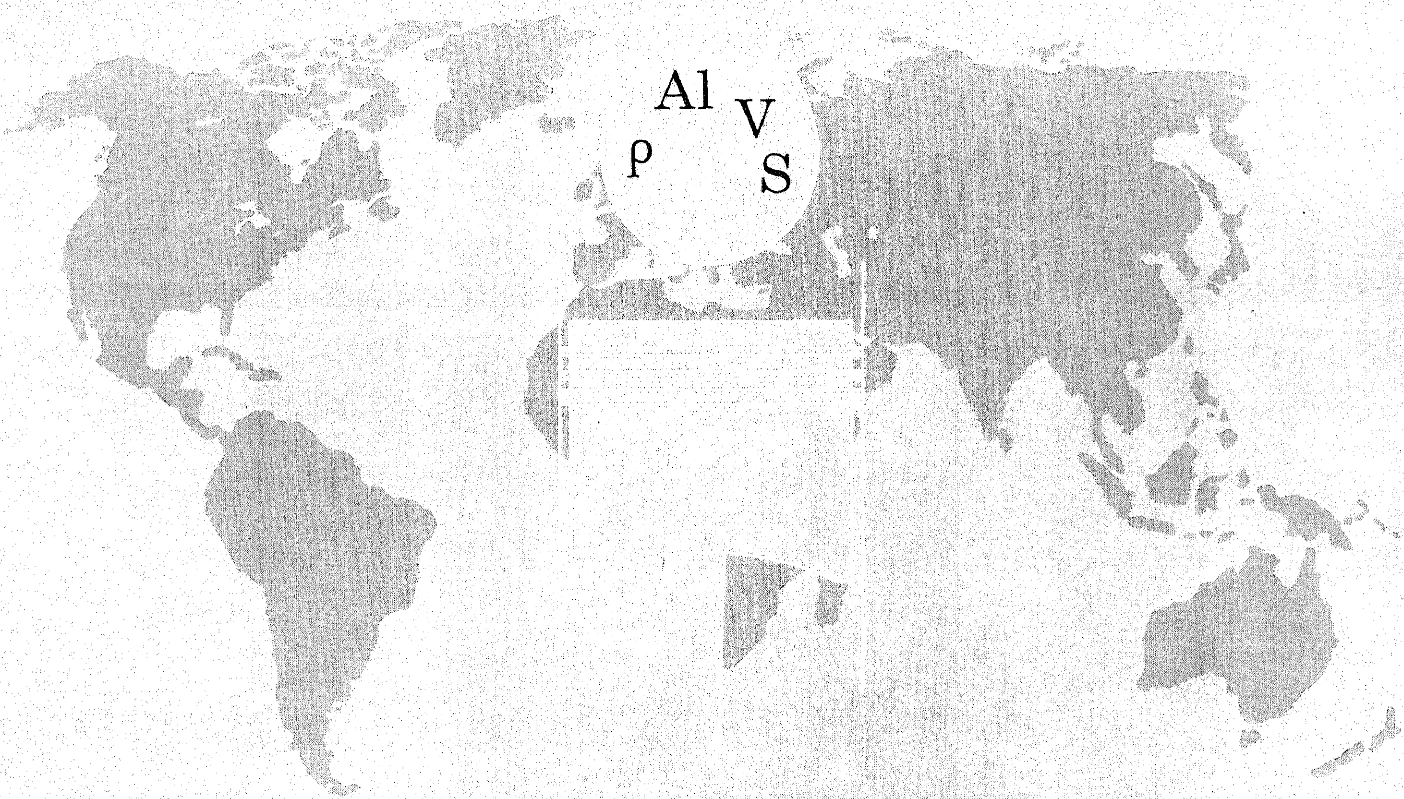
CONSEIL INTERNATIONAL DES MACHINES A COMBUSTION

INTERNATIONAL COUNCIL ON COMBUSTION ENGINES

RECOMMENDATIONS REGARDING

FUEL REQUIREMENTS

FOR DIESEL ENGINES



RECOMMANDATIONS CONCERNANT LES EXIGENCES DES COMBUSTIBLES LIQUIDES POUR MOTEURS DIESEL

CIMAC

Number 11

1990

CIMAC is an international organisation, founded in 1950 by a French initiative, promoting technical and scientific knowledge in the field of internal combustion engines (piston engines and gas turbines). This is achieved by organising 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 are listed in the back of this publication, as are previous CIMAC Recommendations.

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THIRD EDITION*)

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TROISIÈME EDITION*)

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Le présent document a été élaboré par le Groupe de Travail Combustibles Lourds et approuvé par le Comité Permanent le Mai 15 1990.

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SUMMARY

These Recommendations are a further development of earlier CIMAC publications in respect of fuel requirements and although still based on the International Standards Organisation – Specification of Marine Fuels – ISO 8217: 1987, are in some respects more restrictive and include a number of additional characteristics.

Additional information is also given regarding fuel grade selection criteria and the background to some of the less clearly defined characteristics which govern fuel quality.

SOMMAIRE

Les recommandations complètent les précédentes publications CIMAC définissant des limites pour les caractéristiques des fiouls. Bien que basées sur les spécifications I.S.O. pour les fiouls marins – ISO 8217: 1987 – ces recommandations, parfois plus restrictives, introduisent de nouvelles caractéristiques.

Aussi, les critères sélectifs pour les classes de fiouls sont précisés. En arrière plan, on donne des informations sur certaines des caractéristiques les moins bien définies ayant une importance sur la qualité du fioul.

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1. HISTORICAL BACKGROUND

The decreasing quality of residual fuels, experienced worldwide in the past two decades, and the economic incentive to operate larger diesel engines virtually exclusively with low grade fuels, have resulted in an increasing demand for an internationally accepted fuel specification.
The first action to obtain such a marine fuel specification was taken by the British Standards Institution (BSI) and resulted in the BS-MA 100: 1982 standard. Simultaneously, the CIMAC working group on "Future Fuels" began to prepare requirements for residual fuels, specifically for diesel engines. These requirements were published in the professional magazines in January 1982. CIMAC continued its work to develop requirements for heavy fuels, published as CIMAC Recommendations Volume 8 in 1986. In the meantime BSI introduced a proposal for a new international standard to be approved by the International Organisation for Standardization. This has led to ISO 8217: 1987, the first and until now only international standard on heavy fuel, also replacing the original BS-MA 100: 1982 standard.

Further efforts by all concerned with fuel specifications have led to these new Recommendations (nr 11) for Fuel Requirements by CIMAC which now supercede Recommendations Volume 8.

2. SCOPE

The scope of the CIMAC recommendations is intended to cover all fuels for marine and stationary diesel engines. The requirements apply to the fuel as delivered. The recommendations are intended primarily for use by the engine manufacturers in their manuals. This allows engine users to specify fuels suitable for engine type and fuel treatment plant. They are published by the central CIMAC secretariat from which all interested parties can obtain copies.
The recommendations will be periodically reviewed and revised when necessary.

3. RELATION BETWEEN CIMAC REQUIREMENTS AND ISO SPECIFICATIONS

The scope of the two requirements differs because ISO covers marine fuels for steam boilers as well as for diesel engines. The difference can be shown as follows:

ISO	CIMAC
Marine installations: – Diesel engines – Steam boilers	Diesel engines: – Marine installations – Land based installations

Whereas ISO, as an official standards organisation, can only specify characteristics for which official test procedures exist, CIMAC can and may sometimes rely on proposed or proprietary test methods.
However, CIMAC ensures that there are no conflicting requirements, and thus there is a common basis between CIMAC and ISO specifications. All grades and the system of designation are comparable and every CIMAC grade is an ISO grade with some additional or more stringent requirements.

4. GENERAL REQUIREMENTS

The fuels shall be homogeneous mixtures of hydrocarbons derived from petroleum. This shall not preclude the incorporation of small amounts of additives intended to improve some aspects of performance.
The fuel shall not contain contaminants from non-petroleum sources (such as inorganic acids and alkalines) other than those particularly mentioned in the specification.
The properties of the fuels shall not exceed the maximum values nor be less than the minimum values set out in the tables.

5. SAMPLING

Sampling of fuels for analysis should be carried out in accordance with the procedures given in ISO 3170. Additional information on sampling procedures are given in CIMAC Recommendations nr. 9 for Heavy Fuel Treatment.

6. TEST METHODS

The following test methods should be used to determine compliance with the requirements.

6.1. Density:
ISO 3675 – Crude petroleum and liquid petroleum products – Laboratory determination of density or relative density. Hydrometer method. This method is to be used at a temperature between 50 °C and 60 °C and the hydrometer readings converted to 15 °C using ASTM table 53B referred to in ISO 91/1.

6.2. Kinematic viscosity:
ISO 3104 – Petroleum products – Transparent

and opaque liquids – Determination of kinematic viscosity and calculation of dynamic viscosity.

6.3. Flash point:
ISO 2719 – Petroleum products – Determination of flash point. Pensky-Martens closed cup method.

6.4. Pour point:
ISO 3016 – Petroleum oils – Determination of pour point.

6.5. Cloud point:
ISO 3015, Petroleum oils – Determination of cloud point.

6.6. Carbon Residue:
Grades DX and DA:
ISO 4262, Petroleum products – Determination of carbon residue – Ramsbottom method.
All other grades:
ASTM D 4530: Determination of Microcarbon residue. ISO 10370 (provisional)

6.7. Ash:
ISO 6245 – Petroleum products – Determination of ash.

6.8. Sediment by extraction:
ISO 3735, Crude petroleum and fuel oils – Determination of sediment – Extraction method.

6.9. Total sediment after ageing (potential):
IP 375/86'. Total sediment in residual fuel oils. The method IP 390 (proposed ISO 10307) gives two procedures for ageing fuel samples which, when used in combination with IP 375, determine the increase in sediment after heating (see appendix, section 1).

6.10. Water:
ISO 3733 – Petroleum products and bituminous materials – Determination of water – Distillation method.

6.11. Cetane index:
ISO 4262 and IP 380/88' – Calculated Cetane index by four variable equation.

6.12. Cetane number:
ISO 5165, Diesel fuels – Determination of ignition quality – Cetane Method.

6.13. Visual inspection (qualitative):
ASTM D 4176, "Free water and particulate contamination".

6.14. Sulphur:
ISO 8754, Petroleum products – Determination of sulphur content – Non-dispersive X-ray fluorescence method.

6.15. Vanadium:
DIN 51790 (July 1978), part. 1 and 2. Proposed ISO 8691.

6.16. Aluminium + Silicon:
IP 377/88', proposed ISO 10478, Determination of Aluminium + Silicon (see also appendix, section 2).

Note: Ignition properties:
No generally accepted test method is currently available for residual fuels (see appendix, section 3).

7. PRECISION AND THE INTERPRETATION OF TEST RESULTS

The majority of methods, specified in section 6, contain a statement of precision (repeatability and reproducibility) for each test. Attention is drawn to ISO 4259 – Petroleum Products: "Determination and Application of Precision Data in Relation to Methods of Test". This procedure shall be used in all cases of dispute.
It is accepted that in some cases the reproduceability can lead to deviations which are larger than the value of the actual limit.

8. SELECTION OF FUEL GRADES

a) Distillate grades:

DX is a fuel which is suitable for use at ambient temperatures down to –15 °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 designated MGO (Marine Gas Oil) in the marine field.

DB is a general purpose fuel which may contain trace amounts of residual fuel and is intended for engines not specifically designed to burn residual fuels. It is generally designated MDO (Marine Diesel Oil) in the marine field.

DC is a fuel which can contain a significant proportion of residual fuel. Consequently it is unsuitable for installations where engine or fuel treatment plant are not designed for the use of residual fuels.

b) Residual grades:

A 10 and B 10
are available for operation at low ambient temperatures in installations without storage tank heating, where a pour point lower than 24 or 30 °C is necessary.

Of these two grades A 10 has a lower density and a minimum viscosity to increase the probability of good ignition properties.

The range of C 10 up to H 55
are fuels, intended for treatment by a conventional purifier-clarifier centrifuge system. Generally the highest viscosity, allowed by the heating capacity of the installation and the maximum temperature, allowed by the engine design, should be used, except when other parameters take precedence over viscosity in selecting the fuel grade. Of these grades, E 25 has a minimum viscosity limit to increase the probability of reasonable ignition properties.

K 35, K 45 and K 55
are only for use in installations with centrifuges specially designed for higher density fuels.

Requirements 1990 for distillate fuels for diesel engines (as delivered)

		Designation: CIMAC–	DX	DA	DB	DC[2])
Related to	ISO 8217	F–	DMX	DMA	DMB	DMC
Characteristic	Dim.	limit				
Residual inclusion			none	none	some trace	allowed
Density at 15 °C	kg/m³	max	–	890	900	920
Kinematic viscosity at 40 °C	cSt[1])	max min	5.5 1.4	6 1.5	11 2.5	14
Flash point	°C	min	43	60	60	60
Pour point winter[5]) summer	°C	max max	– –	–6 0	0 6	0 6
Cloud point	°C	max	–16			
Carbon residue Ramsbottom on 10% res. Microcarbon	 % m/m % m/m	 max max	 0.20	 0.20	 0.25	 3.00
Ash	% m/m	max	0.01	0.01	0.01	0.03
Sediment by extraction	% m/m	max	–	–	0.02	–
Total sediment	% m/m	max	–	–	–	0.05
Water	% V/V	max	–	–	0.30	0.30
Cetane number[4])		min	45	40	35	35
Visual inspection			clear[3])	clear[3])	may be black	
Sulphur	% m/m	max	1.0	1.5	2.0	2.0
Vanadium	mg/kg	max				100
Aluminium + Silicon	mg/kg	max				25

[1]) 1 cSt = 1 mm^2/sec.
[2]) Note that although predominantly consisting of distillate fuel, the residual oil proportion can be significant (see section 8).
[3]) See 6: visual inspection.
[4]) Cetane index may be used if no cetane improvers are applied. (not for DC)
[5]) Applies to region and season in which fuel is to be stored and used. (upper value winter quality, bottom value summer quality)

Requirements (1990) for residual fuels for diesel engines (as delivered)

Designation:			CIMAC A 10	CIMAC B 10	CIMAC C 10	CIMAC D 15	CIMAC E 25	CIMAC F 25	CIMAC G 35	CIMAC H 35	CIMAC K 35	CIMAC H 45	CIMAC K 45	CIMAC H 55	CIMAC K 55
Related to ISO 8217 (87):		F –	RMA 10	RMB 10	RMC 10	RMD 15	RME 25	RMF 25	RMG 35	RMH 35	RMK 35	RMH 45	RMK 45	RMH 55	–
Characteristic	Dim.	Limit													
Density at 15 °C	kg/m³	max	950	975		980	991		991		1010	991	1010	991	1010
Kinematic viscosity at 100 °C [1]	cSt [2]	max	10			15	25		35			45		55	
		min [4]	6				15								
Flash point	°C	min	60			60	60		60			60		60	
Pour point	°C	max	0 / 6 [3]		24	30	30		30			30		30	
Carbon Residue	% (m/m)	max	12		14	14	15	20	18	22		22		22	
Ash	% (m/m)	max	0.10			0.10	0.10	0.15	0.15			0.15		0.15	
Total sediment after ageing	% (m/m)	max	0.10			0.10	0.10		0.10			0.10		0.10	
Water	% (V/V)	max	0.50			0.80	1.0		1.0			1.0		1.0	
Sulphur	% (m/m)	max	3.5			4.0	5.0		5.0			5.0		5.0	
Vanadium	mg/kg	max	150		300	350	200	500	300	600		600		600	
Aluminium + Silicon	mg/kg	max	80			80	80		80			80		80	
Ignition properties			see appendix, section 3												

[1]) Approximate equivalent viscosities (for information only):

Kinematic viscosity (cSt) at	100 °C	6	10	15	25	35	45	55
Kinematic viscosity (cSt) at	50 °C	22	40	80	180	380	500	700
Sec. Redwood I at	100 °F	165	300	600	1500	3500	5000	7000

[2]) 1cSt = 1 mm²/sec

[3]) Applies to region and season in which fuel is to be stored and used. (upper value winter quality, bottom value summer quality)

[4]) Recommended value only. May be lower if density is also lower. See appendix, part 3

APPENDIX

ADDITIONAL INFORMATION REGARDING SOME PROPERTIES

1. Total Sediment after ageing (potential) (re 6.9)

All residual fuels normally contain a certain amount of sediment or sludge, which may include finely divided particles of agglomerated asphaltenes, coke or adventitious material. The low sediment level generally present will not affect normal operations. Fuels with excessive sediment contents can cause severe difficulties in service.

Note:
Sediment or sludge occurs as a function of three different fuel properties. They are:

Cleanliness
Cleanliness of a fuel is defined as the amount of sediment or sludge at the moment of measurement by the filtration test method IP 375 (86). Some of this sludge may be due to the onset of an instability effect.

Stability
With unstable fuels the amount of sediment or sludge increases significantly with time, or as a result of heating in storage or during transport.
There are two ageing procedures available in the form of the IP 390 method. They determine the potential increase in sediment after
a) 24 h. heating at 100 °C ("physical method")
b) 1 h. heating at 100 °C after addition of cetane ("chemical method")
Investigations are proceeding to determine the merits of both methods to allow for a choice. Pending the outcome of this, either may be applied but the method should be stated. When both methods are used the higher result will be taken as the deciding criteria.

The property "*Total sediment after ageing*" as used in the table is obtained by measuring the cleanliness after applying either of the above ageing procedures. In the case of fuel grade DC the ageing step is omitted, thus only "*Total sediment*" is specified.

Compatibility
Fuels are incompatible if a mixture of two or more fuels produces a blend with an increased amount of sludge. Since compatibility is not a property of the delivered fuel alone, it can not be included in these requirements.

An indication of the compatibility of two fuels can be obtained by means of any cleanliness test, applied to a mixture of the fuels in the intended ratio.
For use on board, the ASTM D 4740 spot-test can give a quick answer for this purpose. Experience, however, has indicated that compatible fuels occasionally fail to pass this test due to deficiencies in the test procedure.
A general problem with compatibility assessment is that samples of both fuels are normally not available in advance. The risk of incompatibility problems should therefore be avoided as much as possible by appropriate design and operation of the fuel storage and treatment installation (see "CIMAC Recommendations Volume 9 for Heavy Fuel Treatment").

2. Aluminium + Silicon (re 6.16)

A new approach has been adopted to indicate the amount of catalyst fines in the fuel which replaces the measurement of Aluminium alone. It provides a closer relationship with the actual catalyst fines content. The new limit will broadly have the same restriction on the overall catalyst fines content.
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.

Also the effectiveness of the fuel treatment is of paramount importance and the imposed limit presumes that the fuel treatment system is designed to optimum standards and operated under optimum conditions.

3. Ignition properties

No accepted 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. The background of this phenomenon stems from the examination of the fundamental aspects of the ignition process. This led to the conclusion that ignition quality should be related to fuel aromaticity, which for this purpose was defined as the percentage of a

fuel's carbon atoms that are located in aromatic structures.
Aromatic molecules increase ignition delay for two reasons: they have a relatively high thermal stability and do not oxidise readily during the ignition process, and they also retard the oxidation of more reactive species. 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, aromaticity is not a straightforward parameter to measure. Fortunately, further work established a correlation between carbon-aromaticity and the density and viscosity of the fuel. This is apparent in the experience that fuels causing ignition trouble often (not always) have a higher density than normally found at the occurring viscosity.
Two formulae have been presented to obtain an indication for ignition delay. That for CCAI, developed by Shell, is a measure for carbon-aromaticity, the relation with ignition delay being empirically confirmed. That for CII (Calculated Ignition Index), developed by BP, has an empirical basis. They are:

$$CCAI = D - 81 - 141 \log\log (V50 + 0.85)$$

$$CCAI = D - 111 - 141 \log\log (V100 + 0.85)$$

$$CII = (270.795 + 0.1038T) - 0.254565\,D + 23.708 \log\log (Vk + 0.7)$$

in which
D = density in kg/m^3 at 15 °C
V50 = kinematic viscosity in cSt at 50 °C
V100 = kinematic viscosity in cSt at 100 °C
Vk = kinematic viscosity in cSt at T °C

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

Several engine manufacturers have published their experiences with ignition quality, mostly by referring to the CCAI of the fuels. It appears that the value above which ignition problems can occur is in the range of 850-890, with an increased probability for a large group of engines in the range of 870-890. For lighter grades, however, (up to about 25 cSt at 100 °C-180 cSt at 50 °C) the value can spread between 840 and 870 so it is preferable to be below a CCAI of 840.
Based on such experiences, some manufacturers specify CCAI limits for their engines, depending on engine type and application.

It has now become clear that the density-viscosity relation does not allow a completely accurate prediction of ignition quality. As a consequence, limiting the calculated carbon aromaticity by means of maximum density and minimum viscosity limits in a specification could be misleading as such limits do not guarantee a certain ignition quality but only increase its probability.
Therefore, in the table only the lighter fuel grades A, B and C 10 and D 15 have a reduced density and only two grades have a limit on minimum viscosity. These grades are presented here with the resulting maximum CCAI values:

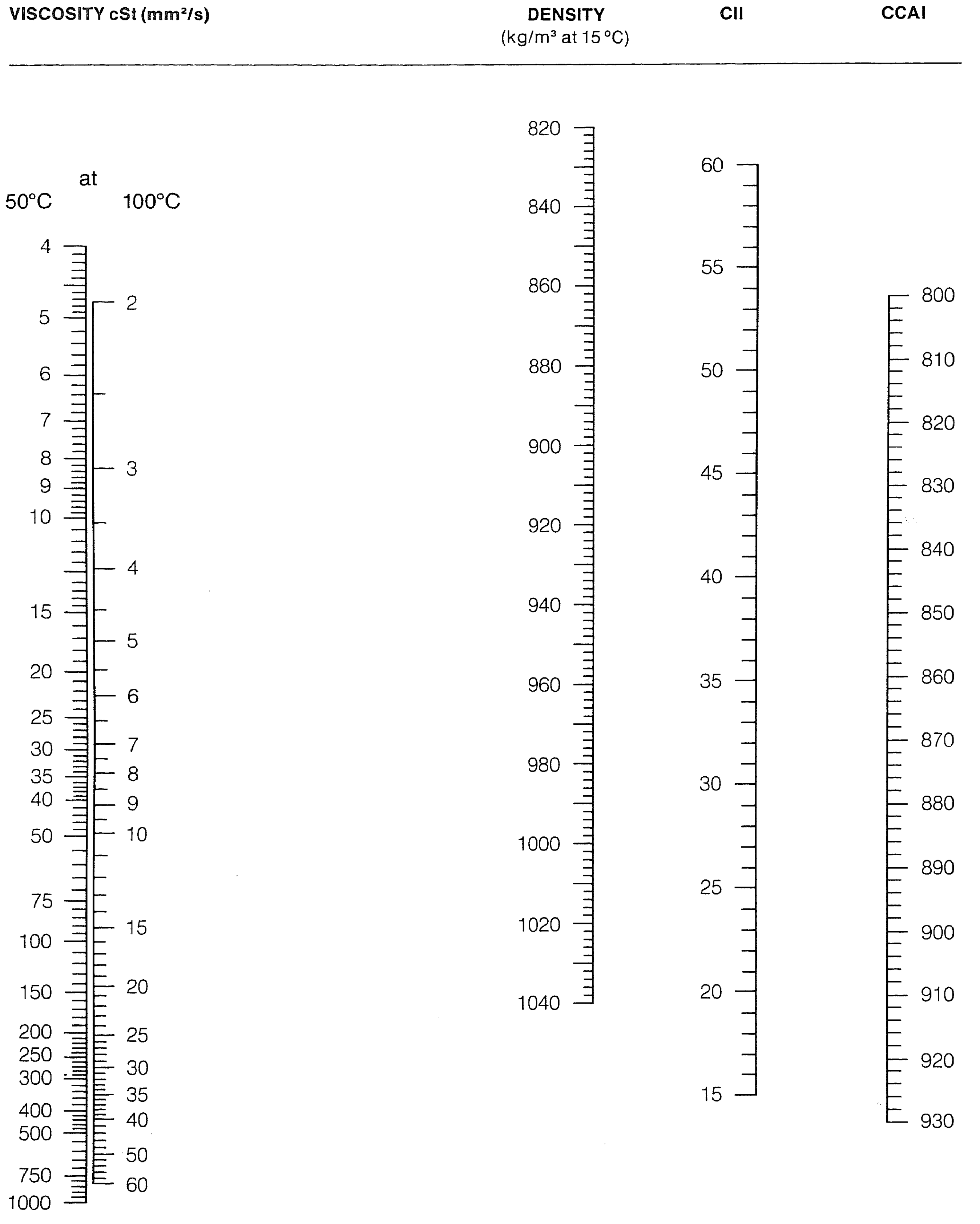
grade	A 10	E 25
density max (kg/m^3)	950	991
viscosity min (cSt)	6	15
CCAI max	850	869

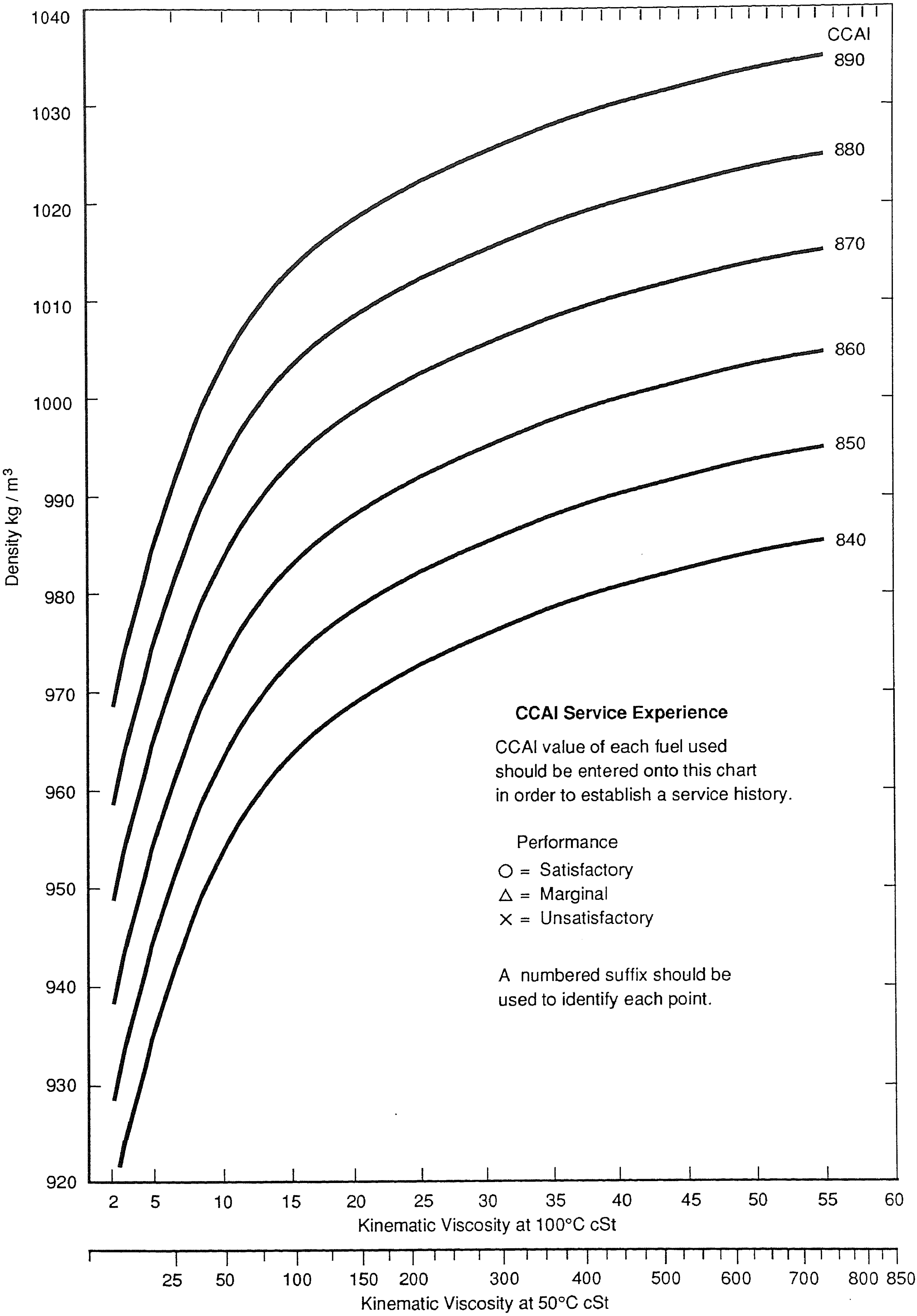
The viscosity may be lower than the min. value specified if the density is sufficiently low so as to ensure that the specified maximum CCAI value is not exceeded.

For all other grades the probability of reasonable ignition quality can only be increased by specifying minimum viscosity in addition to the specified requirements in order to limit the maximum possible CCAI value.

The CCAI value required for a certain engine type and application may be specified by the engine manufacturer or may be obtained by experience. The graph on page 10 is 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 allowable CCAI value.

Nomogram for deriving CCAI and CII




CCAI
890
880
870
860
850
840
Density kg / m3
1040
1030
1020
1010
1000
990
980
970
960
950
940
930
920
2
5
10
15
20
25
30
35
40
45
50
55
60
Kinematic Viscosity at 100°C cSt
25
50
100
150
200
300
400
500
600
700
800
850
Kinematic Viscosity at 50°C cSt
CCAI Service Experience
CCAI value of each fuel used should be entered onto this chart in order to establish a service history.
Performance
○ = Satisfactory
△ = Marginal
× = Unsatisfactory
A numbered suffix should be used to identify each point.

2184/01

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