TECHNICAL REPORT

ISO/TR 18588

First edition
2023-09

Petroleum products — Characterization of marine fuels by viscosity-gravity constant

Produits pétroliers — Caractérisation des combustibles pour la marine par la constante viscosité-gravité

Reference number
ISO/TR 18588:2023(E)

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Published in Switzerland

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Foreword

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This document was prepared by Technical Committee ISO/TC 28, *Petroleum and related products, fuels and lubricants from natural or synthetic sources*, Subcommittee SC 4, *Classifications and specifications*.

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Introduction

On 1 January 2020, MARPOL Annex VI Regulation 14.1 reduced the maximum sulfur (S) content of marine fuels to be used when operating outside an emission control area (ECA) from 3,50 % by mass to 0,50 % by mass. This resulted in a more diverse range of fuel blend formulations being offered to the marine market and an increasing interest by the marine industry in the characterization of petroleum-derived fuels not including fatty acid methyl ester (FAME), in terms of their aromatic or paraffinic nature.

This document provides an indicator for defining whether a petroleum-derived residual fuel which does not include FAME, as supplied to a ship, is more aromatic or paraffinic in nature.

Petroleum products — Characterization of marine fuels by viscosity-gravity constant

1 Scope

This document provides best practices on the calculation and use of an informative indicator for the characterization of fossil residual marine fuels not containing FAME as defined in ISO 8217. This document is based on established guidance used by the petroleum industry to characterize petroleum fractions in terms of their paraffinic, naphthenic or aromatic nature, by their viscosity-gravity constant.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
fatty acid methyl ester
FAME
ester derived by (trans-)esterification of fats and vegetable oils

3.2
very low sulfur fuel oil
VLSFO
marine fuel with a maximum sulfur content of 0,50 % by mass

3.3
high sulfur fuel oil
HSFO
marine fuel with a sulfur content exceeding 0,50 % by mass

4 Characterization of petroleum fuels

4.1 General

Riazi[1] cites two methods for the characterization of petroleum fractions:

— the Bureau of Mines correlation index (BMCI);

— the viscosity-gravity constant (VGC).

4.2 BMCI (or CI)

4.2.1 General

BMCI, often also referred to as correlation index (CI) is used to characterize petroleum fractions/crude oils. Riazi[1] reports that values of BMCI between 0 and 15 indicate a predominantly paraffinic oil. A value of BMCI greater than 50 indicates a predominance of aromatic compounds[2]. According to the CI scale[3], all n-paraffins have a CI value of 0, while cyclohexane (the simplest naphthene), has a CI value of 50, and benzene has a CI value of 100. Using the CI scale, petroleum fractions can be classified as described in Table 1.

Table 1 — Classification of petroleum fractions according to CI values

Nature of petroleum fraction	CI value
Paraffinic (P)	<29,8
Naphthenic (N)	<57,0
Aromatic (A)	>75,0

4.2.2 Calculation of BMCI (or CI)

BMCI (or CI) relies on terms that are not available from the routine testing of marine fuels. It can be determined from Formula (1).

$$I_{BMC} = \frac{48\,640}{T_b} + 473{,}7 \times G_s - 456{,}8 \quad (1)$$

where

I_{BMC} is the Bureau of Mines correlation index;

G_s is the liquid specific gravity at 15,6 °C (60 °F) [see Formula (2)];

T_b is the volume average boiling point, expressed in degree kelvin (K) [see Formula (3)].

G_s can be calculated from the fuel's density as follows:

$$G_s = \frac{\left(\frac{\rho_{15}}{1\,000} - K\right)}{H} \quad (2)$$

where

ρ_{15} is the density at 15 °C, expressed in kilogram per cubic metre (kg/m^3);

H and K are variables the values of which are to be selected from Table 2.

Table 2 — Values of H and K versus G_s

G_s value		H value	K value
min.	max.		
≥0,79	<0,81	0,998 342	0,000 964
≥0,81	<0,83	0,998 492	0,000 842
≥0,83	<0,849 999 9	0,998 641	0,000 718
≥0,849 999 9	<0,875 000 1	0,998 761	0,000 616
≥0,875 000 1	<0,900 000 1	0,998 881	0,000 511
≥0,900 000 1	<1	0,999 011	0,000 394
≥1	<1,1	0,998 861	0,000 544

The volume average boiling point T_b can be calculated from Formula (3):

$$T_b = 9{,}336\,9 \times e^{\left(1{,}651\,4\times10^{-4}\times M + 1{,}410\,3\times G_s - 7{,}515\,2\times10^{-4}\times M\times G_s\right)} \times M^{0{,}536\,9} \times G_s^{-0{,}727\,6} \quad (3)$$

where

T_b is the volume average boiling point, expressed in degree kelvin (K);

G_s is the liquid specific gravity at 15,6 °C (60 °F) [see Formula (2)];

e is the Euler number;

M is a variable, the value of which can be calculated from Formula (4).

$$M = 223{,}56 \times \upsilon_{38}^{(-1{,}243\,5+1{,}122\,8\times G_s)} \times \upsilon_{99}^{(3{,}475\,8-3{,}038\times G_s)} \times G_s^{-0{,}666\,5} \quad (4)$$

where

υ_{38} is the viscosity at 38 °C, expressed in square millimetre per second (mm^2/s);

υ_{99} is the viscosity at 99 °C, expressed in square millimetre per second (mm^2/s).

Hence, the conversion of viscosity at 50 °C, υ_{50}, to viscosity at 38 °C and 99 °C is essential.

Formulae (5) and (6) can be used to convert viscosity at 50 °C to viscosity at 38 °C and 99 °C as follows:

$$\upsilon_{38} = e^{e^{\left\{\ln[\ln(\upsilon_{50}+0{,}7)]+3{,}55\times\ln\left(\frac{273{,}15+50}{273{,}15+38}\right)\right\}}} - 0{,}7 \quad (5)$$

$$\upsilon_{99} = e^{e^{\left\{\ln[\ln(\upsilon_{50}+0{,}7)]+3{,}55\times\ln\left(\frac{273{,}15+50}{273{,}15+99}\right)\right\}}} - 0{,}7 \quad (6)$$

where υ_{50} is the viscosity at 50 °C, expressed in square millimetre per second (mm^2/s).

4.2.3 Algorithm to calculate BMCI (or CI)

The algorithm to calculate BMCI (or CI) can be found in Annex A.

4.3 Viscosity-gravity constant

4.3.1 General

Viscosity-gravity constant (VGC) is based on an empirical relation developed between Saybolt viscosity (SUS) and specific gravity through a constant. Later, the formulae were revised, using density and viscosity for the calculation of VGC, as in ASTM D2501. Both Riazi and ASTM D2501 refer to VGC values for paraffinic and aromatic hydrocarbons. According to Speight[4], VGC varies for paraffinic hydrocarbons from 0,74 to 0,75, for naphthenic from 0,89 to 0,94, and for aromatics from 0,95 to 1,13. ASTM D2501 refers to values of VGC near 0,800 indicating samples of paraffinic character, while values close to 1,00 indicate a preponderance of aromatic structures.

4.3.2 Calculation of VGC

The original formulae used Saybolt Universal Seconds and specific gravity as the input parameters. The formulae were later transformed to use kinematic viscosity in excess of 4 mm^2/s at 40 °C and density at 15 °C as input parameters. The formulae were further revised to use kinematic viscosity in excess of either 5,5 mm^2/s at 40 °C or 0,8 mm^2/s at 100 °C [see Formula (7)].

$$C_{VG} = \frac{\rho_{15} - 0{,}108 - 0{,}1255 \times \lg(\eta - 0{,}8)}{0{,}90 - 0{,}097 \times \lg(\eta - 0{,}8)} \tag{7}$$

where

C_{VG} is the viscosity-gravity constant;

ρ_{15} is the density of the fuel at 15 °C, expressed in gram per millilitre (g/ml);

η is the viscosity of the fuel at 100 °C, expressed in square millimetre per second (mm^2/s).

NOTE ASTM D2501 also includes a formula to calculate VGC based on viscosity at 40 °C.

Formula (8) can be used to convert viscosity at 50 °C to viscosity at 100 °C as follows:

$$\eta = e^{e^{\left\{\ln[\ln(\upsilon_{50}+0{,}7)]+3{,}55\times\ln\left(\frac{273{,}15+50}{273{,}15+100}\right)\right\}}} - 0{,}7 \tag{8}$$

where

η is the viscosity of the fuel at 100 °C, expressed in square millimetre per second (mm^2/s);

e is the Euler number;

υ_{50} is the viscosity at 50 °C, expressed in square millimetre per second (mm^2/s).

4.3.3 Algorithm to calculate VGC

The algorithm to calculate VGC can be found in Annex A.

5 Samples data analysis

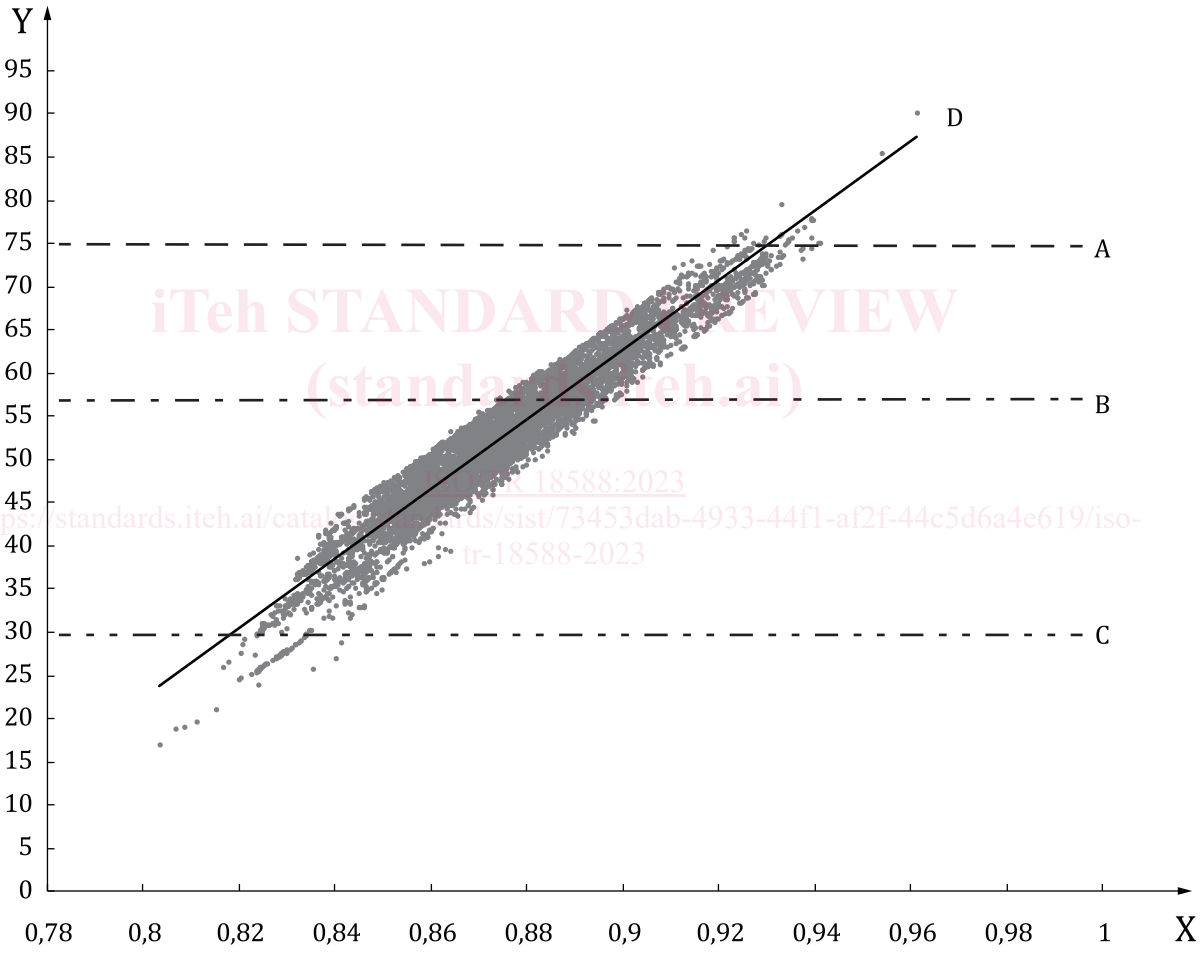
5.1 General

The following figures are based on a sample subset of residual marine fuels of approximately 9 000 samples with S content ≤0,50 % by mass and approximately 1 000 samples with S content ≥0,50 % by mass drawn in 2021.

NOTE Similar results were obtained for two other data sets of samples.

5.2 BMCI versus VGC and density for fuels with S content ≤0,50 % by mass

Figure 1 plots the calculated BMCI value of residual fuel oils with a sulfur content at or below 0,50 % by mass [very low sulfur fuel oil (VLSFO)] against the calculated VGC value.



Key

X C_{VG}
Y I_{BMC}
A I_{BMC} = 75
B I_{BMC} = 57
C I_{BMC} = 29,8
D regression line

Figure 1 — Plot of BMCI against VGC for VLSFO