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

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

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Foreword

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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.

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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 \(1\)](#).

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

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:

$$G_s = \frac{\left(\frac{\rho_{15}}{1000} - K \right)}{H} \tag{2}$$

where

ρ_{15} is the density at 15 °C, expressed in kilogram per cubic metre (kg/m³);

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.		
$\geq 0,79$	$< 0,81$	0,998 342	0,000 964
$\geq 0,81$	$< 0,83$	0,998 492	0,000 842
$\geq 0,83$	$< 0,849\ 999\ 9$	0,998 641	0,000 718
$\geq 0,849\ 999\ 9$	$< 0,875\ 000\ 1$	0,998 761	0,000 616
$\geq 0,875\ 000\ 1$	$< 0,900\ 000\ 1$	0,998 881	0,000 511
$\geq 0,900\ 000\ 1$	< 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 \(3\)](#):

$$T_b = 9,336\ 9 \times e^{(1,651\ 4 \times 10^{-4} \times M + 1,410\ 3 \times G_s - 7,515\ 2 \times 10^{-4} \times M \times G_s)} \times M^{0,536\ 9} \times G_s^{-0,727\ 6} \quad (3)$$

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 \(4\)](#).

$$M = 223,56 \times v_{38}^{(-1,2435 + 1,1228 \times G_s)} \times v_{99}^{(3,4758 - 3,038 \times G_s)} \times G_s^{-0,666\ 5} \quad (4)$$

where

v_{38} is the viscosity at 38 °C, expressed in square millimetre per second (mm²/s);

v_{99} is the viscosity at 99 °C, expressed in square millimetre per second (mm²/s).

Hence, the conversion of viscosity at 50 °C, v_{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:

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

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

where v_{50} is the viscosity at 50 °C, expressed in square millimetre per second (mm²/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 mm²/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 mm²/s at 40 °C or 0,8 mm²/s at 100 °C [see [Formula \(7\)](#)].

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

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 (mm²/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:

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

where

η is the viscosity of the fuel at 100 °C, expressed in square millimetre per second (mm²/s);

e is the Euler number;

v_{50} is the viscosity at 50 °C, expressed in square millimetre per second (mm²/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 $\leq 0,50$ % by mass and approximately 1 000 samples with S content $\geq 0,50$ % 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 $\leq 0,50$ % 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.

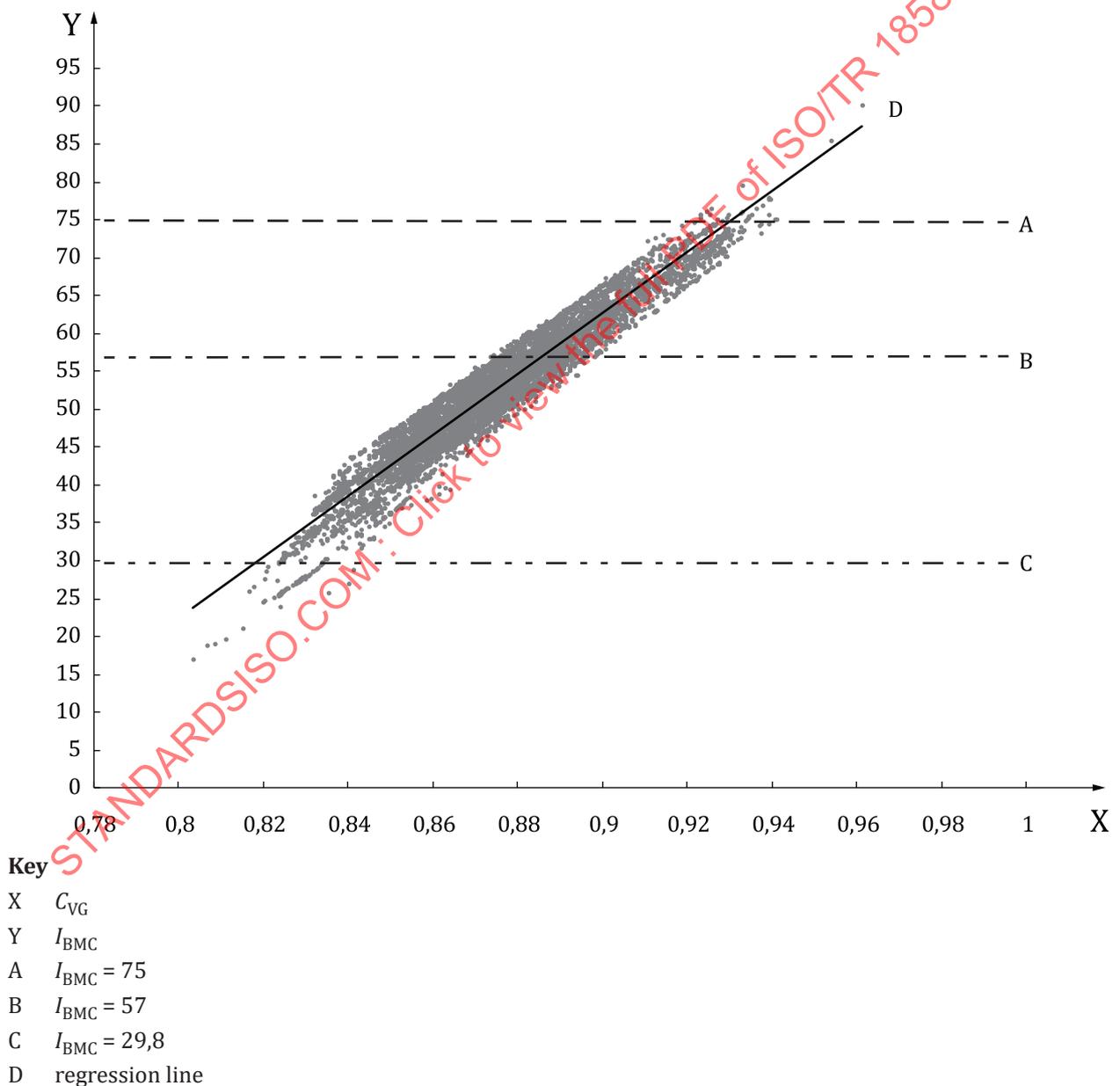
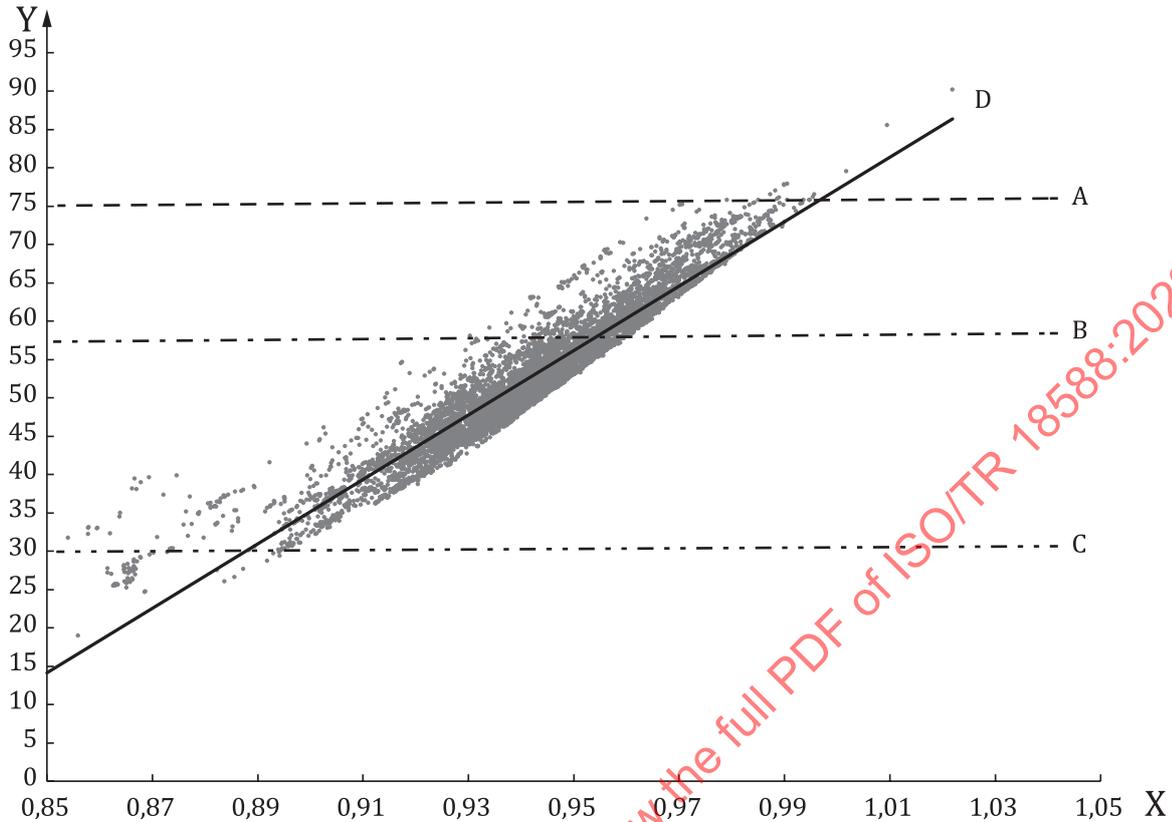


Figure 1 — Plot of BMCI against VGC for VLSFO

Figure 2 plots the calculated BMCI value against density. Using the BMCI scale reference values, the corresponding VGC values and density can be calculated (see Table 3).



Key

- X density of the fuel at 15 °C, expressed in kilogram per cubic metre x 10⁻³
- Y I_{BMC}
- A $I_{BMC} = 75$
- B $I_{BMC} = 57$
- C $I_{BMC} = 29,8$
- D regression line

Figure 2 — Plot of BMCI against density for VLSFO

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

Figure 3 and Figure 4 plot the calculated BMCI value of residual fuel oils with a sulfur content above 0,50 % by mass [high sulfur fuel oil (HSFO)], respectively, against the calculated VGC value and density. Using the BMCI scale reference values, the corresponding VGC and density values can be calculated (see Table 3).

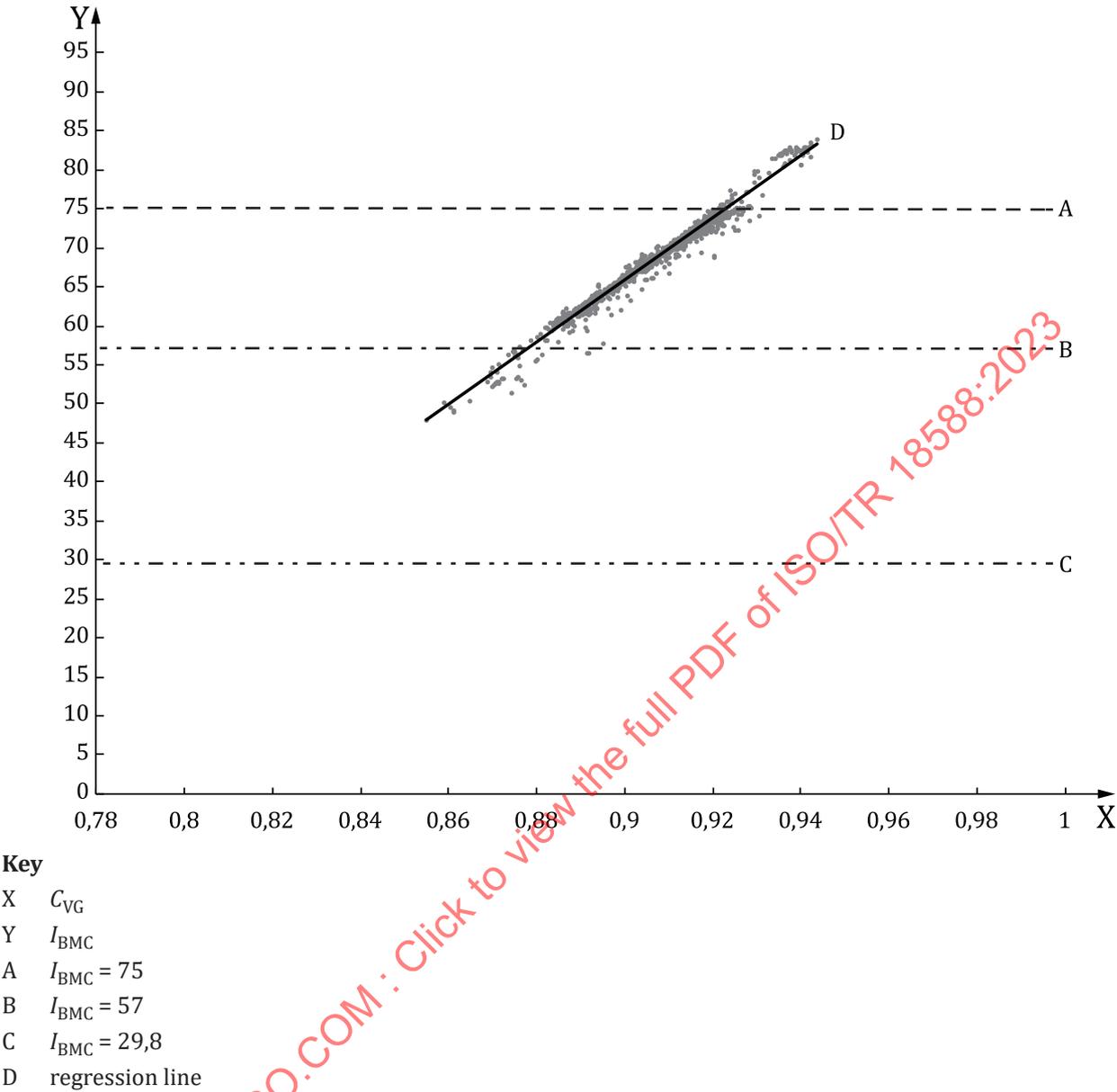
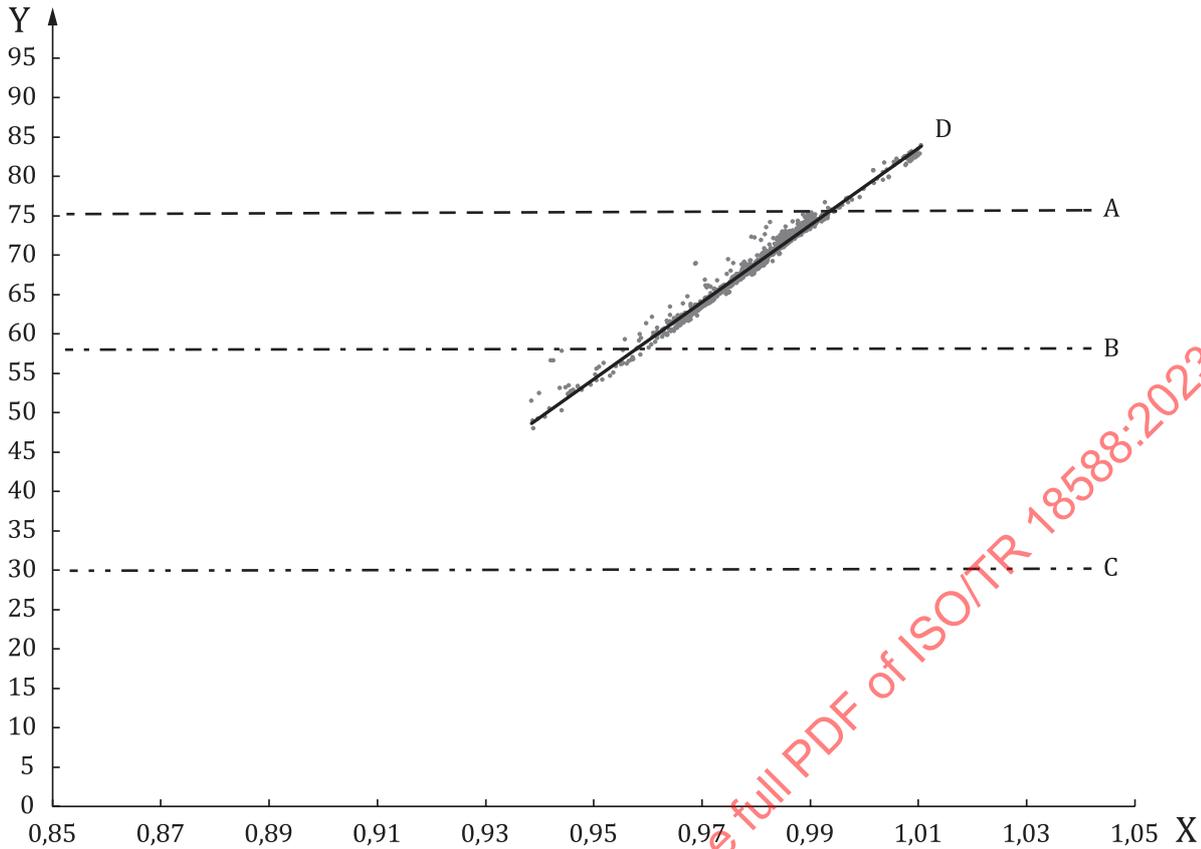


Figure 3 — Plot of BMCI against VGC for HSFO



Key

- X density of the fuel at 15 °C, expressed in kilogram per cubic metre x 10⁻³
- Y I_{BMC}
- A $I_{BMC} = 75$
- B $I_{BMC} = 57$
- C $I_{BMC} = 29,8$
- D regression line

Figure 4 — Plot of BMCI against density for HSFO

5.4 Significance and use of VGC

Table 3 is derived from Figures 1 to 4. Table 3 presents the BMCI reference values against the corresponding VGC and density values for all samples, as well as VLSFO and HSFO separately.

Table 3 — BMCI reference values against corresponding VGC and density

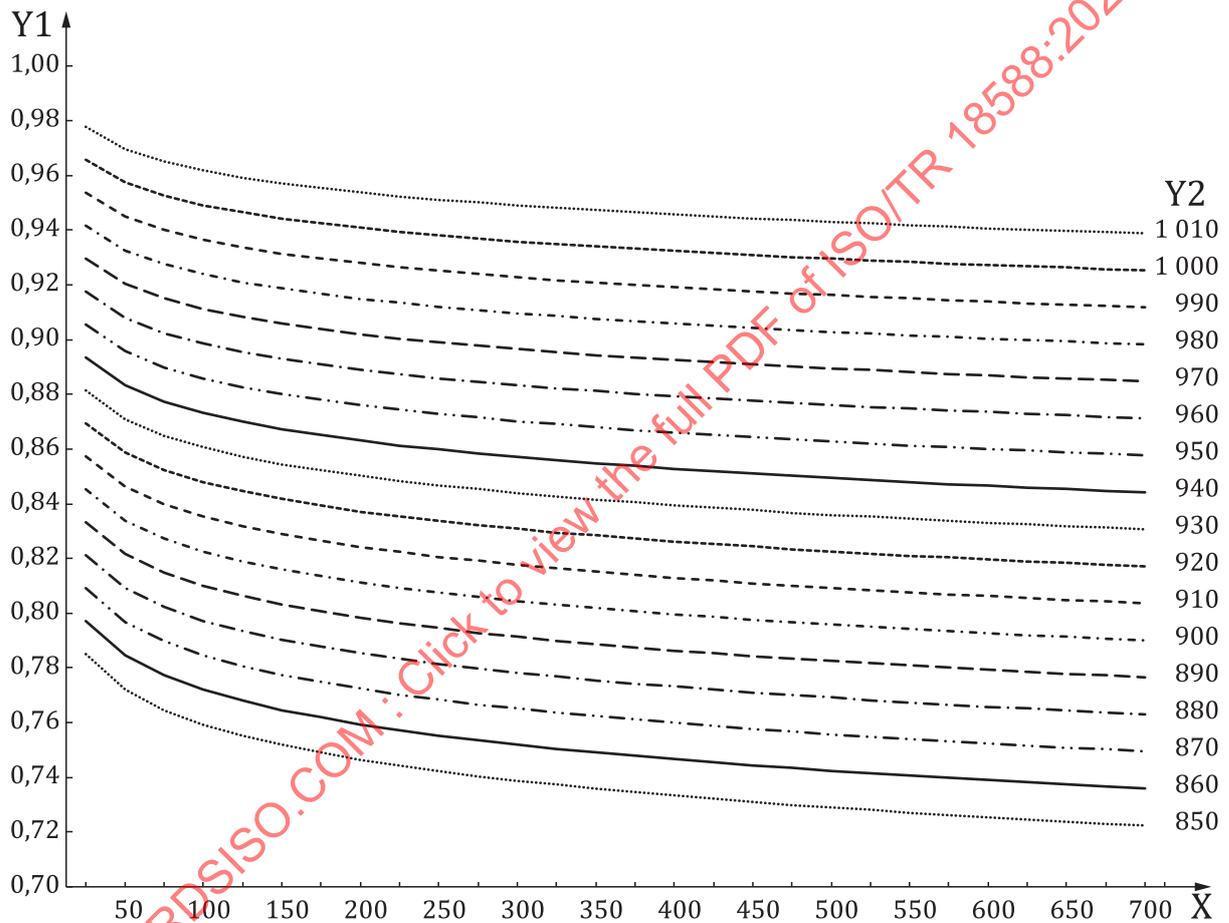
Nature of petroleum fraction	BMCI	All samples		VLSFO		HSFO	
		VGC	Density kg/m ³	VGC	Density kg/m ³	VGC	Density kg/m ³
Paraffinic (P)	<29,8	0,82	888	0,82	887	0,81	900
Naphthenic (N)	<57,0	0,88	952	0,89	952	0,88	956
Aromatic (A)	>75,0	0,92	994	0,93	995	0,92	992

Correlating BMCI values with densities of fuel oils shows that density is an existing characteristic that can be used to obtain an indication of the nature of the fuel oil irrespective of the sulfur content of the fuel. Densities near or below 900 kg/m³ indicate the fuel to lean towards being paraffinic in nature.

Values of VGC near 0,80 or below indicate the fuel leaning towards being paraffinic in nature, while values greater than 0,92 indicate a preponderance of aromatic structures, irrespective of the sulfur content of the fuel, which is in line with Riazi stating $VGC > 0,95$ to be indicative for the aromatic nature of the fraction.

VGC values are not hard cut limits, but are used to evaluate whether a product leans more towards being paraffinic or aromatic in nature when comparing one product to another. Calculation of VGC according to ASTM D2501 is less complex than a calculation of BMCI. By applying the VGC formula to the standard density and viscosity tested parameters of a residual marine fuel, values of the VGC can provide an indication of the character of the fuel.

Figure 5 plots VGC versus the viscosity of the fuel for different densities.



Key

- X viscosity at 50 °C, expressed in square millimetre per second (mm²/s)
- Y1 viscosity-gravity constant
- Y2 density of the fuel at 15 °C, expressed in kilogram per cubic metre (kg/m³)

Figure 5 — Plot of VGC against viscosity, 25 mm²/s to 700 mm²/s for different densities

EXAMPLE 1 The calculated VGC for a residual fuel with viscosity of 100 mm²/s at 50 °C and density of 900,0 kg/m³ is 0,82, which is indicative for the fuel leaning more towards being paraffinic in nature.

EXAMPLE 2 The calculated VGC for a residual fuel with viscosity of 180 mm²/s at 50 °C and density of 990,0 kg/m³ is 0,93, which is indicative for the fuel leaning more towards being aromatic in nature.

Annex A (informative)

Algorithms to calculate SG, BMCI and VGC

A.1 Algorithm to calculate SG

$SG = (IF(AND(\rho_{15}/1\ 000 > = 0,81; \rho_{15}/1\ 000 < = 0,83);((\rho_{15}/1\ 000-0,000\ 842)/0,998\ 492);$
 $IF(AND(\rho_{15}/1\ 000 > 0,83; \rho_{15}/1\ 000 < = 0,85);((\rho_{15}/1\ 000-0,000\ 718)/0,998\ 641);$
 $IF(AND(\rho_{15}/1\ 000 > 0,85; \rho_{15}/1\ 000 < = 0,875);(\rho_{15}/1\ 000-0,000\ 616)/0,998\ 761);$
 $IF(AND(\rho_{15}/1\ 000 > 0,875; \rho_{15}/1\ 000 < = 0,9);((\rho_{15}/1\ 000-0,000\ 511)/0,998\ 881);$
 $IF(AND(\rho_{15}/1\ 000 > 0,9; \rho_{15}/1\ 000 < = 1);((\rho_{15}/1\ 000-0,000\ 394)/0,999\ 011);$
 $IF(AND(\rho_{15}/1\ 000 > 1; \rho_{15}/1\ 000 < = 1,1);((\rho_{15}/1\ 000-0,000\ 544)/0,998\ 861);Error"))))))$

where ρ_{15} is the density at 15 °C, expressed in kilogram per cubic metre (kg/m³).

A.2 Algorithm to calculate BMCI

$BMCI = 48\ 640/(9,336\ 9*(EXP((1,651\ 4*0,000\ 1*(223,56*(EXP(EXP((LN(LN(\eta +0,7)))$
 $+3,55*LN((273,15+50)/(273,15+38))))-0,7)^{-1,243\ 5+1,122\ 8*((\rho_{15}/1\ 000-0,000\ 394)/0,999\ 011))$
 $* (EXP(EXP((LN(LN(\eta +0,7))) +3,55*LN((273,15+50)/(273,15+99))))-0,7)^{(3,475\ 8-3,038*((\rho_{15}/1\ 000-$
 $0,000\ 394)/0,999\ 011))*((\rho_{15}/1\ 000-0,000\ 394)/0,999\ 011)^{-0,666\ 5}+1,410\ 3*((\rho_{15}/1\ 000-$
 $0,000\ 394)/0,999\ 011)-7,515\ 2*0,000\ 1*(223,56*(EXP(EXP((LN(LN(\eta +0,7))) +3,55*LN((273,15+50)/$
 $(273,15+38))))-0,7)^{-1,243\ 5+1,122\ 8*((\rho_{15}/1\ 000-0,000\ 394)/0,999\ 011)) * (EXP(EXP((LN(LN(\eta$
 $+0,7))) +3,55*LN((273,15+50)/(273,15+99))))-0,7)^{(3,475\ 8-3,038*((\rho_{15}/1\ 000-$
 $0,000\ 394)/0,999\ 011))*((\rho_{15}/1\ 000-0,000\ 394)/0,999\ 011)^{-0,666\ 5))*((\rho_{15}/1\ 000-$
 $0,000\ 394)/0,999\ 011))* (223,56*(EXP(EXP((LN(LN(\eta +0,7))) +3,55*LN((273,15+50)/(273,15+38))))-$
 $0,7)^{-1,243\ 5+1,122\ 8*((\rho_{15}/1\ 000-0,000\ 394)/0,999\ 011))* (EXP(EXP((LN(LN(\eta +0,7)))$
 $+3,55*LN((273,15+50)/(273,15+99))))-0,7)^{(3,475\ 8-3,038*((\rho_{15}/1\ 000-0,000\ 394)/0,999\ 011))$
 $* ((\rho_{15}/1\ 000-0,000\ 394)/0,999\ 011)^{-0,666\ 5})^{0,536\ 9*((\rho_{15}/1\ 000-0,000\ 394)/0,999\ 011)^{-0,727\ 6})$
 $+473,7*((\rho_{15}/1\ 000-0,000\ 394)/0,999\ 011)-456,8$

where

ρ_{15} is the density at 15 °C, expressed in kilogram per cubic metre (kg/m³);

η is the viscosity at 100 °C, expressed in square millimetre per second (mm²/s).