SLOVENSKI STANDARD
kSIST-TP FprCEN/TR 16389:2025

01-maj-2025

Goriva za motorna vozila - Parafinsko dizelsko gorivo in mešanice s FAME - Ozadje zahtevanih parametrov, njihove omejitve ter določevanje

Automotive fuels - Paraffinic diesel fuel and blends with FAME - Background to the parameters required and their respective limits and determination

Kraftstoff für Kraftfahrzeuge - Paraffinischer Dieselkraftstoff und Kraftstoff-Mischungen - Hintergrund zu den erforderlichen Parametern, den entsprechenden Grenzwerten und deren Bestimmung

Carburants pour automobiles - Gazole paraffinique et mélanges d'EMAG - Historique sur la définition des paramètres requis, de leurs limites et de leurs déterminations respectives

Ta slovenski standard je istoveten z: **FprCEN/TR 16389**

ICS:

75.160.20	Tekoča goriva	Liquid fuels

kSIST-TP FprCEN/TR 16389:2025 **en**

TECHNICAL REPORT

RAPPORT TECHNIQUE

TECHNISCHER REPORT

FINAL DRAFT
FprCEN/TR 16389

March 2025

ICS

Will supersede CEN/TR 16389:2023

English Version

Automotive fuels - Paraffinic diesel fuel and blends with FAME - Background to the parameters required and their respective limits and determination

Carburants pour automobiles - Gazole paraffinique et mélanges d'EMAG - Historique sur la définition des paramètres requis, de leurs limites et de leurs déterminations respectives

Kraftstoff für Kraftfahrzeuge - Paraffinischer Dieselkraftstoff und Kraftstoff-Mischungen - Hintergrund zu den erforderlichen Parametern, den entsprechenden Grenzwerten und deren Bestimmung

This draft Technical Report is submitted to CEN members for Vote. It has been drawn up by the Technical Committee CEN/TC 19.

CEN members are the national standards bodies of Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Republic of North Macedonia, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Türkiye and United Kingdom.

Recipients of this draft are invited to submit, with their comments, notification of any relevant patent rights of which they are aware and to provide supporting documentation.

Warning : This document is not a Technical Report. It is distributed for review and comments. It is subject to change without notice and shall not be referred to as a Technical Report.

EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

Ref. No. FprCEN/TR 16389:2025 E

Contents

Page

European foreword

This document (FprCEN/TR 16389:2025) has been prepared by Technical Committee CEN/TC 19 “Gaseous and liquid fuels, lubricants and related products of petroleum, synthetic and biological origin”, the secretariat of which is held by NEN.

This document is currently submitted to the Vote on TR.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. CEN shall not be held responsible for identifying any or all such patent rights.

This document will supersede CEN/TR 16389:2023.

The fourth version of this document has been updated after the revision of EN 15940:2023. In this update, several editorial and technical improvements have been made.

Any feedback and questions on this document should be directed to the users’ national standards body. A complete listing of these bodies can be found on the CEN website.

1 Scope

This document explains the requirements and test methods for paraffinic diesel fuel from synthesis or hydrotreatment containing up to 7,0 % (V/V) Fatty Acid Methyl Ester (FAME). Synthesis refers to XTL processes where X refers to various feedstocks for example Gas (G), Biomass (B) or Coal (C) and TL stands for To-Liquid. In this document the term hydrotreatment includes all catalytic processes where hydrogen is used. Hydrotreatment of oils and fats from plant, animal or any other biological origin yield paraffinic diesel fuel for example Hydrotreated Vegetable Oil (HVO) or Hydroprocessed Esters and Fatty Acids (HEFA). Paraffinic diesel fuel can be blended with up to 7,0 % (V/V) fatty acid methyl ester (FAME). This document provides background information to the final text of EN 15940:2023 [1] and gives guidance and explanations to the producers, blenders, marketers and users of paraffinic automotive diesel fuel.

Paraffinic diesel fuel is a high quality, clean burning fuel with virtually no sulfur and aromatics. Paraffinic diesel fuel can be used in diesel engines, also to reduce regulated emissions. In order to have the greatest possible emissions reduction, a specific calibration is needed. Some types of paraffinic diesel fuel, at present notably HVO, can also offer a meaningful contribution to the target of increased non-crude derived and/or renewable content in the transportation fuel pool.

For general diesel engine operation, durability and warranty, paraffinic automotive diesel fuel needs a validation step to confirm the compatibility of the fuel with the vehicle, which for some existing engines still needs to be done. The vehicle manufacturer needs to be consulted before use.

NOTE 1 This document is directly related to EN 15940 and will be updated once further publications take place.

NOTE 2 Paraffinic diesel fuel is also used as a blending component in automotive diesel fuel. In that case, composition and properties of the final blends are defined by relevant fuel specification standards.

NOTE 3 For the purposes of this document, the terms “% (m/m)” and “% (V/V)” are used to represent respectively the mass fraction and the volume fraction.

2 Normative references

There are no normative references in this document.

3 Terms and definitions

No terms and definitions are listed in this document.

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

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

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

4 EN 15940, *Automotive fuels - Paraffinic diesel fuel from synthesis or hydrotreatment - Requirements and test methods*

4.1 Parameters included

This document gives further detailed information about requirements and parameters as defined in EN 15940:2023 [1].

All parameters discussed in this document are based on the paraffinic nature of XTL and HVO and the use of FAME complying with EN 14214:2019 [2] as a blending component. The test methods precisions are presented in Table 1.

Table 1 — Precision of the methods to paraffinic diesel fuel and conventional diesel fuel

<table>
<tr><th>Property</th><th>Unit</th><th>Test method</th><th colspan="3">EN 15940 [1] and EN 590 [3] Precision</th></tr>
<tr><td colspan="6">Methods whose precision statement includes paraffinic diesel fuel and conventional diesel fuel</td></tr>
<tr><td rowspan="10">Cetane number</td><td rowspan="10"></td><td rowspan="6">EN ISO 5165:1998 [4]</td><td>Average cetane number level [a]</td><td>Repeatability</td><td>Reproducibility
(R = 0,125× CN - 2,2)</td></tr>
<tr><td>40</td><td>0,8</td><td>2,8</td></tr>
<tr><td>44</td><td>0,9</td><td>3,3</td></tr>
<tr><td>48</td><td>0,9</td><td>3,8</td></tr>
<tr><td>52</td><td>0,9</td><td>4,3</td></tr>
<tr><td>56</td><td>1,0</td><td>4,8</td></tr>
<tr><td>EN 15195:2023 [5]</td><td colspan="3">$r = 0{,}013\ 80 \times X$
$R = 0{,}046\ 82 \times X$</td></tr>
<tr><td>EN 16906:2017 [6]</td><td colspan="3">$r = 1{,}474\ 2 + 0{,}004\ 3 \times X$
$R = -1{,}054\ 2 + 0{,}069\ 2 \times X$</td></tr>
<tr><td>EN 17155:2018 [7]</td><td colspan="3">$r = 0{,}002\ 931 \times (X)^{1{,}47}$
$R = 0{,}006\ 407 \times (X)^{1{,}47}$</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td rowspan="2">Density at 15 °C</td><td rowspan="2">kg/m^3</td><td>EN ISO 3675:1998 [8]</td><td colspan="3">r = 0,5 kg/m^3
R =1,2 kg/m^3</td></tr>
<tr><td>EN ISO 12185:1996 [9]</td><td colspan="3">r =0,2 kg/m^3
R =0,5 kg/m^3</td></tr>
<tr><td>Flash point</td><td>°C</td><td>EN ISO 2719:2016 [10]</td><td colspan="3">$r = 0{,}029 \times X$
$R = 0{,}071 \times X$</td></tr>
<tr><td rowspan="2">Viscosity at 40 °C</td><td rowspan="2">mm^2/s</td><td>EN ISO 3104:2020 [11]</td><td colspan="3">$r = 0{,}004\ 3 \times (X + 1)$
$R = 0{,}008\ 2 \times (X + 1)$</td></tr>
<tr><td>ISO 23581:2020 [12]</td><td colspan="3">$r = 0{,}010\ 5 - 0{,}000\ 3 \times X$
$R = 0{,}034\ 6 + 0{,}005 \times X$</td></tr>
</table>

Property	**Unit**	**Test method**	**EN 15940 [1] and EN 590 [3] Precision**			
Distillation	°C or % recovered	EN ISO 3405:2019 [13]	% recovered	Repeatability °C	Reproducibility °C	
			IBP	3,3	5,6	
			5	r1+0,66	R1+1,11	
			10	r1	R1	
			20	r1	R1	
			30 to 70	r1	R1	
			80	r1	R1	
			90	r1	R1-1,22	
			95	r1	R1-0,94	
			FBP	3,9	7,2	
			Each of the variables r1 and R1 is a constant function of the slope, ΔC/ΔV, at each distillation point in question, with values calculated from: r1 = 0,864 (ΔC/ΔV) + 1,214; R1 = 1,736 (ΔC/ΔV) + 1,994.			
		EN ISO 3924:2019 [14]	% recovered	Repeatability °C	Reproducibility °C	
			IBP	$0{,}011 \times X^b$	$0{,}066 \times X^b$	
			5 %	0,0032×(X+100)	0,015 × (X+100)	
			10 % to 40 %	0,8	0,013 ×(X+100)	
			50 % to 90 %	1,0	4,3	
			95%	1,2	5,0	
			FBP	3,2	11,8	
		EN 17306:2023 [15]		Repeatability	Reproducibility	Valid range
			IBP	r = 3,9	R = 6,0	145 °C – 195 °C
			T5	r = T × 0,011 94	R= T × 0,017 2	175 °C – 250 °C
			T10	r = T × 0,009 54	R = T × 0,017 7	160 °C – 265 °C
			T20	r = T × 0,009 32	R = T × 0,011 7	180 °C – 275 °C
			T30	r = T × 0,007 82	R = T × 0,012 2	190 °C – 285 °C
			T40	r = T × 0,008 22	R = T × 0,012 2	200 °C – 290 °C
			T50	r = T × 0,006 14	R = T × 0,010 3	170 °C – 295 °C
			T60	r = T × 0,005 34	R = T × 0,009 2	220 °C – 305 °C
			T70	r = T × 0,004 05	R = T × 0,008 4	230 °C – 315 °C
			T80	r = T × 0,004 41	R = T × 0,008 4	240 °C – 325 °C
			T90	r = T × 0,004 1	R = T × 0,008 1	180 °C – 340 °C
			T95	r = 2,03	R = 3,23	260 °C – 360 °C
			FBP	r = 3,93	R = 7,7	195 °C – 365 °C

<table>
<tr><th>Property</th><th>Unit</th><th>Test method</th><th colspan="3">EN 15940 [1] and EN 590 [3] Precision</th></tr>
<tr><td>Lubricity, corrected wear scar diameter (WSD) at 60 °C</td><td>µm</td><td>EN ISO 12156-1:2023[16]</td><td colspan="3">r = 0,085 × (1 138 –X)
R = 0,119 × (1 138 – X)</td></tr>
<tr><td>FAME content</td><td>% (V/V)</td><td>EN 14078:2014 [17]</td><td colspan="3">Overall r is between 0,1 % to 0,5 %
Overall R is between 0,5 % to 1,5 %</td></tr>
<tr><td rowspan="2">Sulfur content</td><td rowspan="2">mg/kg</td><td>EN ISO 20846:2019 [18]</td><td colspan="3">range 3 to 60 mg/kg
r = 0,055 3 × X + 0,55
R = 0,112 0 × X + 1,12</td></tr>
<tr><td>EN ISO 20884:2019 [19]</td><td colspan="3">range 5 to 60 mg/kg
r =1,7 + 0,024 8 × X
R = 1,9 + 0,120 1 × X</td></tr>
<tr><td>Carbon residue (on 10 % distillation residue)</td><td>% (m/m)</td><td>EN ISO 10370:2014 [20]</td><td colspan="3">r = 0,077 × $X^{2/3}$
R = 0,245 1 × $X^{2/3}$</td></tr>
<tr><td rowspan="3">Ash content</td><td rowspan="3">% (m/m)</td><td rowspan="3">EN ISO 6245:2002 [21]</td><td>Ash content</td><td>r</td><td>R</td></tr>
<tr><td>0,001-0,079</td><td>0,003</td><td>0,005</td></tr>
<tr><td>0,08-0,180</td><td>0,007</td><td>0,024</td></tr>
<tr><td>Water content</td><td>mg/kg</td><td>EN ISO 12937:2000 [22]</td><td colspan="3">range 0,003 % (m/m) to 0,100 %
r = 0,018 74 × $X^{0,5}$
R = 0,068 77 × $X^{0,5}$</td></tr>
<tr><td>Total contamination</td><td>mg/kg</td><td>EN 12662:2014 [23]</td><td colspan="3">r = 0,064 4 × X +1,609 9
R = 0,164 4 × X + 4,111 0</td></tr>
<tr><td>Copper strip corrosion (3 h at 50 °C)</td><td>rating</td><td>EN ISO 2160:1998 [24]</td><td colspan="3">no generally acceptable method for determining precision</td></tr>
</table>

<table>
<tr><th>Property</th><th>Unit</th><th>Test method</th><th colspan="3">EN 15940 [1] and EN 590 [3] Precision</th></tr>
<tr><td rowspan="11">Oxidation stability</td><td rowspan="9">g/m³</td><td rowspan="9">EN ISO 12205;1996 [25]</td><td colspan="3">$r = 5{,}4 \times (X/10)^{0{,}25}$
$R = 10{,}6 \times (X/10)^{0{,}25}$
where C is total insoluble matter:</td></tr>
<tr><td>Insoluble matter (C), g/m³</td><td>Repeatability (r)</td><td>Reproducibility (R)</td></tr>
<tr><td>1</td><td>3,0</td><td>6,0</td></tr>
<tr><td>5</td><td>4,5</td><td>8,9</td></tr>
<tr><td>10</td><td>5,4</td><td>10,6</td></tr>
<tr><td>15</td><td>6,0</td><td>11,7</td></tr>
<tr><td>20</td><td>6,4</td><td>12,6</td></tr>
<tr><td>25</td><td>6,8</td><td>13,3</td></tr>
<tr><td>30</td><td>7,1</td><td>14,0</td></tr>
<tr><td>h</td><td>EN 15751:2014 [26]</td><td colspan="3">$r = 0{,}220\ 27 + 0{,}043\ 44 \times X$
$R = 0{,}372\ 69 + 0{,}190\ 38 \times X$
where X represents the average of the two results in hours</td></tr>
<tr><td>min</td><td>EN 16091;2022 [27]</td><td colspan="3">$r = 0{,}028\ 8 \times X + 0{,}496\ 5$
$R = 0{,}086\ 3 \times X + 1{,}377\ 2$
where X represents the average of the two results in minutes</td></tr>
<tr><td rowspan="2">Cloud point</td><td rowspan="2">°C</td><td>EN ISO 3015:2019 [28]</td><td colspan="3">$r = 1{,}433\ 9 - 0{,}007\ 1 \times X$
$R = 3{,}958\ 5 + 0{,}066\ 1 \times X$
where X is the mean of two results being compared
Manual method: r and R reported for distilled oils:
r = 2
R = 4</td></tr>
<tr><td>EN ISO 22995:2019 [29]</td><td colspan="3">r = 1,1 °C
R = 2,5 °C</td></tr>
<tr><td>Manganese content</td><td>mg/l</td><td>EN 16576:2014 [30]</td><td colspan="3">$r = 0{,}035\ 2 \times X + 0{,}029\ 0$
$R = 0{,}114\ 7 \times X + 0{,}094\ 4$
where X represents the mean of the two results expressed in mg/l</td></tr>
<tr><td rowspan="2">CFPP[c]</td><td rowspan="2">°C</td><td>EN 116 :2015 [31]</td><td colspan="3">$r = 1{,}2 - 0{,}027 \times X$
$R = 3{,}0 - 0{,}060 \times X$</td></tr>
<tr><td>EN 16329:2022 [32]</td><td colspan="3">$r = 1{,}1 - 0{,}033 \times X$
$R = 1{,}7 - 0{,}052 \times X$</td></tr>
</table>

Property	Unit	Test method	EN 15940 [1] and EN 590 [3] Precision	
Methods that have a different precision for paraffinic diesel fuel and conventional diesel fuel				
			EN 15940 Precision	**EN 590 precision**
Total aromatics content	% (*m*/*m*)	EN 12916:2022 [33] total aromatic	range 0,8 to 1,8 % (*m*/*m*) r=0,039 1 × X + 0,007 22 R=0,171 3 × X + 0,346 9	range 7 to 42 % (*m*/*m*) r=0,040 × X -0,070 R=0,172 × X – 1,094

a Values for CNs intermediate to those listed above can be obtained by linear interpolation.

b Where X is the average of the two results in degrees Celsius.

c CFPP precisions have been improved and will be corrected in next revision of the EN 15940.

4.2 Considerations on the parameters

4.2.1 Cetane number

The cetane number is a measure of the compression ignition behaviour of a fuel, which influences cold startability, exhaust emissions and combustion noise. The cetane number is measured on a test engine or a Derived Cetane Number (DCN) is determined from a correlation with ignition delay as measured in a constant volume combustion chamber. The cetane number reflects the combination of the natural self-ignition properties and the effects of cetane improver additives.

The choice of two different classes originates from the differences between the processes which results in different chemical composition. The processes are the low-temperature and high-temperature Fischer-Tropsch (LTFT and HTFT) and Hydrogenated Vegetable Oils (HVO). Because a higher cetane number is an advantage for some applications, the specific distinction between automotive diesel complying with EN 590:2022 [class (minimum cetane of 51) and a high-cetane fuel (minimum 70) has been incorporated in EN 15940:2023 [1].

GTL and HVO are highly paraffinic. LTFT GTL and HVO consist of linear and branched paraffins and have very high cetane numbers in excess of 70. Generally, a high cetane number leads to a reduction in white smoke, noise, engine misfire, emissions and improved cold starting in some engines, especially in engines without pilot injection. HTFT GTL will in general be produced with a cetane between 52 and 65, as this paraffinic fuel also contains significant quantities of cyclo-paraffins. In earlier discussions, a maximum cetane number would be desirable by the OEMs, but it was not introduced in the standard. It is difficult to adjust the production process to limit high cetane number in paraffinic fuels.

The OEMs wished to have a certain band in order to tune the engine where possible. The original band was 55 to 70. Because 55 was really borderline for the HTFT producers, the minimum was lowered to 51 and the maximum to 66 in order to preserve the band width. With this decision it left a four-point gap (66 to 70), so it was decided to delete the maximum on class B. There are two classes: Class A with minimum cetane number 70 and Class B with minimum cetane number 51. Either of the classes do not have a maximum limit for cetane number.

For a European Standard, all referenced test methods need to be applicable to paraffinic fuels and have valid precision statements.

EN 15940:2023 [1] referenced four different test methods for cetane number test methods; EN ISO 5165:1998 (CRF engine) [4], EN 15195:2023 (IQT) [5], EN 16906:2017 (BASF engine) [6] and EN 17155:2018 (ICN) [7].

EN ISO 5165 is the method using the CFR cetane engine and EN 16906 is the method using the BASF engine. EN 15195 is derived cetane by combustion in a constant volume chamber and, specifically using the Ignition Quality Tester or IQT apparatus, EN 15195 directly measures the ignition delay under prescribed conditions from which a derived cetane number (DCN) is calculated via a correlation to cetane number. EN 17155 is a test method for the quantitative determination of the indicated cetane number (ICN).

All four cetane number methods cover conventional and paraffinic diesel fuels.

CEN/TC 19 decided that EN 15195 is the method to be used in cases of dispute due to the significantly better precision of EN 15195 over the other methods at the higher cetane numbers. This was agreed to even though this is a derived test method and not a direct measurement in an engine.

During the update process of EN 15940 in 2022 it was agreed to remove subclause 5.6.3 and Annex A (precision statement), because EN 15195:2014 was also under an update process and it was agreed that an optional equation in the annex was removed in 2023 [5].

Cetane index is a calculated value that approximates the ‘natural’ cetane of a fuel. Cetane index is linked to arctic climate requirements of automotive diesel fuel. However, the cetane index as it stands now, cannot be applied to paraffinic diesel fuels since XTL and HVO fuels were not part of the database underpinning the empirical correlation. Cetane index has not been incorporated in EN 15940.

4.2.2 Density

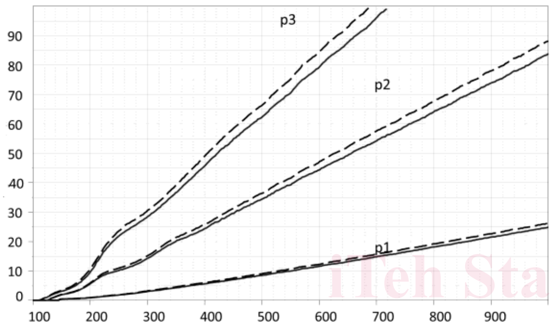
Generally, paraffins have a lower density than aromatic hydrocarbons and consequently, the density of highly paraffinic XTL/HVO diesel is lower than that of conventional diesel fuel (765 kg/m^3 to 810 kg/m^3 compared to 815kg/m^3 to 845 kg/m^3 for temperate grades of conventional diesel fuels). The presence of aromatics in conventional diesel fuel results in a higher density fuel.

The diesel fuel injection is controlled volumetrically or by timing of the solenoid valve. Variations in fuel density (and viscosity) result in variations in engine power and, consequently, in engine emissions and fuel consumption. Therefore, in order to optimize engine performance and tailpipe emissions, OEMs prefers both minimum and maximum density limits to be defined in a fairly narrow range. Moreover, the (volumetric) injection quantity is a control parameter for other emission control systems like the exhaust gas recirculation (EGR). Variations in fuel density therefore result in non-optimal EGR-rates for a given load and speed point in the engine map and, as a consequence, influence the exhaust emission characteristics.

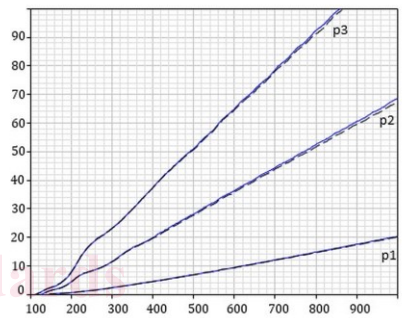
Engine and vehicle manufacturers prefer a narrow range of density for good driveability not exceeding 40 kg/m^3. For durability, a minimum density limit, and for optimized exhaust emission characteristics, a maximum density limit, is important. Diesel fuel categories 3, 4 and 5 of the WWFC 2019 which are defined for markets with more stringent emission requirements restrict the density range from 815 kg/m^3 to 840 kg/m^3, with the option to relax the lower density limit to 800 kg/m^3 for fuel used under low temperature conditions (cloud point below -10 °C).

The impact of the lower density of paraffinic fuels on the gravimetric injection amount depends on the injection principle. For passenger cars, many injectors are designed according to the servo principle with a full ballistic behaviour. In such applications, the gravimetric injection amount is only marginally reduced despite density of paraffinic fuels is 6 % to 7 % lower. For energising times up to 1 000 µs (microsecond), i.e. before the lift stop of the nozzle needle is reached, lower density affects fuel flow through the injector orifices and results in a faster and slightly stronger lift of the nozzle needle (Bernoulli equation). Consequently, the distance that the needle needs to travel for closing is increased. For a given injection timing, changed needle opening and closing behaviour allows a slightly higher volume of fuel to be injected. Under ballistic operating conditions, the increased volumetric injection amount is inversely proportional to fuel density. For paraffinic fuels, the volume injected is approximately increased by 6 % to 7 %, fairly compensating for the lower density and thus corresponding to a gravimetric injection amount of ±1 % compared to standard diesel fuel. Considering the higher inferior heating value of paraffinic fuels (around 44,1 MJ/kg compared to 42,9 MJ/kg for standard diesel) the same gravimetric injection amount results in an approx. 2,8 % higher engine power for paraffinic fuels under part load conditions (see Figure 1).

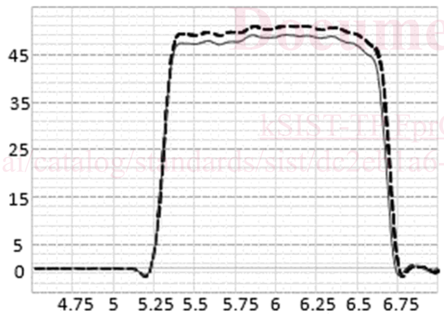
In the non-ballistic operating area of diesel injectors, typically above injection timings of 1 000 µs, the increase of the volumetric injection amount is smaller and does usually not exceed 3 %, thus not fully compensating for the lower density of paraffinic fuels. Such conditions are more typical of full power operation, as might be found on heavy duty vehicle applications. The higher injected volume compensates for approximately half of the density related loss in fuel energy only. Considering again the higher inferior heating value of paraffinic fuels, the injected energy is only slightly reduced and engine performance remains largely unchanged. Older mechanical fuel injection system designs are frequently volume (piston stroke) metered, so will lose gravimetric injection quantity in proportion to density.



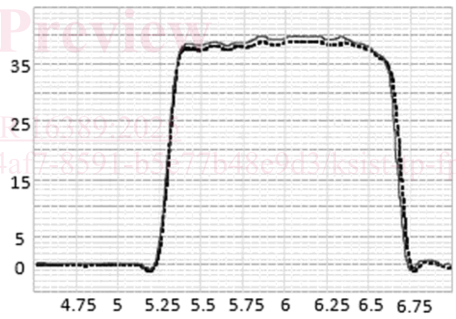
a)



b)



c)



d)

Key

solid line	conventional diesel fuel EN 590
dotted line	paraffinic diesel fuel EN 15940
X-axis (1a)	energising time [µs]
Y-axis (1a)	volumetric injection quantity [mm^3/stroke]
X-axis (1b)	energising time [µs]
Y-axis (1b)	gravimetric injection quantity [mg/stoke]
X-axis (1c)	energising time [ms]
Y-axis (1c)	volumetric flow rate [cm^3/s]
X-axis (1d)	energising time [ms]
Y-axis (1d)	mass flow rate [g/s]

Figure 1 — Volumetric (1a) and gravimetric (1b) injection map at different pressure levels (p1 to p3), volumetric (1c) and gravimetric injection rate (1d) at maximum pressure (p3), presented by the example of the Bosch passenger car injector CRI2.25

The Task Force investigated the effect of temperature on density, based on work done by the PTB (Physical Technical Institute) Braunschweig, Germany. The work is summarized in Annex B of EN 15940:2023.

4.2.3 Flash point

Flash point of a diesel fuel is defined as the lowest temperature at which fuel vapours above the liquid will ignite upon exposure to an ignition source. It is used to classify fuels for transport and storage according to hazard level; minimum flash point temperatures are (legally) required for proper safety and handling of the fuel. Flash point varies inversely with the fuel's volatility.

Flashpoint is a legal requirement for diesel grade fuels. As the flash point of a diesel fuel is associated with the light (lower boiling) material, a diesel fuel with too much light material (shorter carbon chain length molecules) will have a low flash point and it will be hazardous to handle.

Generally, the flash point of neat FAME (soy, rapeseed and palm) fuels is higher than that of paraffinic diesel and conventional crude-derived diesel fuels.

The flash point in EN 15940 has been defined as "Above 55 °C" as in EN 590. Most of the paraffinic diesel fuels have a flashpoint above 60 °C and as such are not required to be labelled as flammable[1]. The higher flashpoint allows for the use of such fuels in marine applications. More data is given in the chapter on IBP and cavitation.

4.2.4 Viscosity

Viscosity is a measure of a fuel's resistance to flow and affects the performance of diesel fuel pumps and injection systems. Low viscosity also has an influence on sliding by changing hydrodynamic contacts, e.g., bearings of camshafts, rollers, etc. Also, mixed contacts, e.g., piston in cylinder, can be adversely affected. Moreover, increased leaking in pressure sealing contacts such as between plunger and guide results in additional heat generation and in reduced injected fuel quantities. Higher temperature associated with low viscosity increases the risk of cavitation and deposit formation. High viscosities on the other hand can reduce fuel flow rates, especially at low ambient temperatures, resulting in insufficient fuel flow and affecting cold start. The pressure build-up in non pressure-controlled systems like unit injectors is also increased imposing additional stress on system components.

Viscosity is related to fuel spray atomisation and it is thus required that a fuel has a certain viscosity range to avoid incomplete combustion which could be associated with poor atomisation of the fuel. If the viscosity is too low, the injection spray is too soft and will not penetrate far enough into the cylinder and loss of power will occur.

The effects of temperature on kinematic viscosity are plotted in Figure 2 for a range of diesel fuels as well as RME based FAME. The graph has nonlinear axes following the practice of ASTM D341 [35]. This approach permits the kinematic viscosity of petroleum fluids to be plotted as a straight line, the slope of which indicates variation with temperature. The results indicate that the relative effect of temperature on kinematic viscosity is similar for each of the petroleum fuels, i.e., the dependency of viscosity on temperature of HVO are virtually identical to summer and winter conventional diesel fuel, as well as Swedish class 1 diesel fuel with and without 5 % (V/V) FAME.

The kinematic viscosity of pure RME based FAME is appreciably higher than any of the petroleum-based fuels. In addition, the slope of the line for pure FAME is slightly lower, i.e., it is slightly less sensitive to the effects of increasing temperature than conventional diesel fuel. FAME fuel blends generally have improved lubricity; however, their higher viscosity levels tend to form larger droplets on injection which can cause poor combustion and increased exhaust smoke under certain operating conditions. At FAME blending levels up to 7 % by volume, the suggested limits provide an acceptable level of fuel system

[1] EU Classification, Labelling and Packaging of Substances and Mixtures Regulation (no 1272/2008) classifies substances and mixtures as flammable where they have a flashpoint of up to 60 °C.