



**International
Standard**

ISO 23581

**Petroleum products and related
products — Determination of
kinematic viscosity — Method by
Stabinger type viscometer**

*Produits pétroliers et produits connexes - Détermination de
la viscosité cinématique - Méthode avec un viscosimètre type
Stabinger*

**Second edition
2024-05**

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 28, *Petroleum and related products, fuels and lubricants from natural or synthetic sources*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 19, *Gaseous and liquid fuels, lubricants and related products of petroleum, synthetic and biological origin*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 23581:2020), which has been technically revised.

The main changes are as follows:

- base oils, formulated oils, jet fuels and residual fuel oils have been included in the scope;
- the apparatus description, sample handling procedures and determinability criteria have been updated to accommodate the new scope.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Petroleum products and related products — Determination of kinematic viscosity — Method by Stabinger type viscometer

WARNING — The use of this document can involve hazardous materials, operations and equipment. This document does not purport to address all of the safety problems associated with its use. It is the responsibility of users of this document to take appropriate measures to ensure the safety and health of personnel prior to application of this document and fulfil other applicable requirements for this purpose.

1 Scope

This document specifies a procedure for the determination of kinematic viscosity, ν , by calculation from dynamic viscosity, η , and density, ρ , of both transparent and opaque liquid petroleum products and crude oils using the Stabinger type viscometer.

The result obtained using the procedure described in this document depends on the rheological behaviour of the sample. This document is predominantly applicable to liquids whose shear stress and shear rate are proportional (Newtonian flow behaviour). If the viscosity changes significantly with the shear rate, comparison with other measuring methods is not possible except at similar shear rates.

The precision has been determined only for the materials, density ranges and temperatures described in [Clause 13](#). The test method can be applied to a wider range of viscosity, density, temperature and materials. It is possible that the precision and bias are applicable for materials which are not listed in [Clause 13](#).

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

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

ISO 3170, *Petroleum liquids — Manual sampling*

ISO 3171, *Petroleum liquids — Automatic pipeline sampling*

ISO 12185, *Crude petroleum and petroleum products — Determination of density — Oscillating U-tube method*

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 dynamic viscosity

η

ratio of the applied shear stress to the resulting shear rate of a liquid

3.2

kinematic viscosity

ν

ratio of the *dynamic viscosity* (3.1) to the *density* (3.3) of a liquid at the same temperature and pressure

Note 1 to entry: The kinematic viscosity is a measure of a liquid's resistance to flow under gravity.

3.3

density

ρ

mass of a substance divided by its volume at a given temperature

3.4

determinability

d

quantitative measure of the variability associated with the same operator in a given laboratory obtaining successive determined values using the same apparatus for a series of operations leading to a single result

Note 1 to entry: Determinability is the difference between two such single determined values that would be exceeded about 5 % of the time (one case in 20 in the long run) in the normal and correct operation of the test method.

3.5

test specimen

portion or volume of the sample obtained from the laboratory sample, which is delivered to the measuring cells

4 Principle

A test specimen is introduced into the measuring cells, at a controlled and known temperature. The measuring cells consist of a pair of rotating concentric cylinders and an oscillating U-tube. The dynamic viscosity is determined from the equilibrium rotational speed of the inner cylinder under the influence of the shear stress of the test specimen and an eddy current brake in conjunction with adjustment data. The density is determined by the oscillation frequency of the U-tube in conjunction with adjustment data. The kinematic viscosity is calculated by dividing the dynamic viscosity by the density.

5 Reagents and materials

5.1 Cleaning solvent, able to remove the sample from the measuring cell after the measurement and completely miscible with all constituents of the sample. Commercially available volatile petroleum spirit or cleaner's naphtha of technical grade or better have been proven suitable as cleaning solvents.

5.2 Drying solvent, highly volatile and miscible with the cleaning solvent, shall be filtered before use and shall be of an appropriate purity so that no residues remain in the instrument. *n*-Hexane, *n*-heptane (recommended due to lower toxicity) or, depending on the sample, concentrated ethanol (≥ 96 %) are suitable.

NOTE 1 A separate drying solvent is not needed if the cleaning solvent also meets the requirements of the drying solvent.

NOTE 2 When measuring residual fuel, asphaltic material can be removed by pre-washing with an aromatic solvent (e.g. toluene or xylene).

5.3 Compressed air, oil-free and filtered with a dew point lower than the lowest measuring cell temperature at which the instrument should be dried.

The pressure should be limited to 100 kPa.

It is also possible to use inert gases, for example technical nitrogen. The requirements given for compressed air are also valid here.

5.4 Certified reference liquids, for kinematic viscosity and density, which shall be identical to the reference standards for kinematic viscosity and density cited in ISO 3104 and ISO 12185, respectively.

5.5 Reference thermometer and probe, for verification of the temperature calibration.

The measuring uncertainty of the reference thermometer, including the probe, shall not exceed 0,01 °C. The resolution shall be at least 0,001 °C.

The probe used for the calibration (with an adapter if necessary) shall have a shape which fits the geometry of the viscosity cell. The probe replaces the measuring system (tube and measuring rotor).

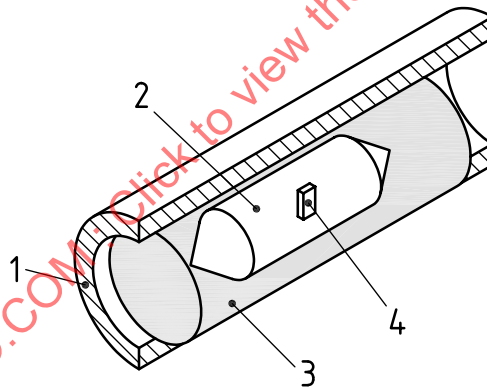
6 Apparatus

Usual laboratory apparatus and glassware shall be used, in particular the following.

6.1 Stabinger type viscometer.

6.1.1 Viscosity measurement

The Stabinger type viscometer is a concentric rotating viscometer, containing an outer rotor and an inner rotor (see [Figure 1](#)). The small concentric gap between these rotors is filled with the sample. The outer rotor is driven at constant speed, which makes the inner rotor rotate due to the sample's viscosity. The lightweight inner rotor is centred in the heavier sample due to the centrifugal forces. The equilibrated speed ratio depends on the driving viscous shear force and the opposing magnetic induction force (eddy current). The dynamic viscosity is a function of the equilibrated speed ratio and adjustment constants. The kinematic viscosity is obtained by dividing the measured dynamic viscosity by the measured density.



Key

- | | | | |
|---|------------------------------|---|--------------|
| 1 | outer rotor (constant speed) | 3 | sample fluid |
| 2 | inner rotor (measured speed) | 4 | magnet |

Figure 1 — Viscosity cell

6.1.2 Density measurement

The Stabinger type viscometer has an integrated density measurement based on the oscillating U-tube principle. The sample-filled U-tube is oscillated and the instrument calculates the density from the measured natural frequency of the filled tube using adjustment factors. The viscosity-dependent error of this procedure is corrected using the measured viscosity value.

6.1.3 Temperature control

The Stabinger type viscometer has an integrated temperature control which keeps the viscosity and density measurement at the same temperature.

Using Peltier elements, a highly conductive measuring cell block which surrounds the measuring cells is set to the target temperature with a stability of $\pm 0,005$ °C over the whole temperature range at the position of the viscosity cell.

The measurement uncertainty of the temperature calibration ($k = 2$; 95 % confidence level) shall be within $\pm 0,03$ °C over the range from 15 °C to 100 °C and within $\pm 0,05$ °C outside this range.

6.2 Syringes.

Commercially available syringes with a Luer tip of at least 5 ml in volume shall be used. The user shall ensure full chemical compatibility of the syringe construction materials with all sample and cleaning liquids by consulting the manufacturer's documentation.

6.3 Flow-through or pressure adapter.

A flow-through or a pressure adapter may be used as an alternative to a syringe for introduction of the test specimen into the measuring cells. Such adapters apply either pressure or suction to the test specimen, therefore, care shall be taken to avoid the formation of bubbles. The user shall ensure full chemical compatibility of the flow-through or pressure adapter construction materials with all sample and cleaning liquids by consulting the manufacturer's documentation.

6.4 Hot filling adapter.

A hot filling adapter maintains the sample temperature during manual introduction of the test specimen into the measuring cells. It may be added to the Stabinger type viscometer to improve the flow of the test specimen and prevent precipitation of wax crystals while filling and cleaning the measuring cells.

6.5 Sample changer or sample handler.

The sample changer or sample handler shall be designed to ensure and maintain the integrity of the test specimen before and during the analysis. It shall be capable of transferring a representative aliquot of the test specimen into the measuring cells. It shall be able to mimic the procedure for sample handling described in [7.2](#). The sample changer or sample handler may have heating capability, if required.

6.6 Screen.

If a screen is used, it shall have an aperture of 75 μm to remove particles from the sample.

6.7 Magnet.

If an external magnet is used, the magnet shall be strong enough to remove ferromagnetic materials from the sample. Magnetic stirring rods may be used.

6.8 Ultrasonic bath, unheated.

To dissipate and remove air or gas bubbles from the sample, an ultrasonic bath may be used prior to analysis. The bath should be sized to hold the container(s) placed inside, and operate at an operating frequency between 25 kHz and 60 kHz and a typical power output of ≤ 100 W. Ultrasonic baths with operating frequencies and power outputs outside this range may be used, but it is in the responsibility of the user to confirm via a data comparison study that the results obtained after sample preparation with and without such baths do not show significant deviations.

7 Sampling and sample handling

7.1 Sampling

Samples shall be taken as described in ISO 3170 or ISO 3171.

NOTE National regulations can apply.

7.2 Sample handling

7.2.1 General sample handling

For samples such as viscous lube oils that are likely to contain air or gas bubbles, an ultrasonic bath (6.8) without the heater turned on (if so equipped) may be used for typically 1 min to dissipate the bubbles.

The test specimen shall be obtained as follows:

- a) The laboratory sample shall be mixed if it is not homogeneous. The mixing should be carried out in a closed, pressurized container or at sub-ambient temperatures to avoid the loss of volatile material.
- b) The test specimen may be drawn with an appropriate syringe from a properly mixed laboratory sample. Alternatively, the sample may be delivered from the mixing container directly to the measuring cells by means of a flow-through or pressure adapter or sample changer or sample handler, provided that the proper attachments and connecting tubes are used. For waxy or other samples with high pour point, before drawing the test specimen, heat the sample to the desired temperature, which shall be high enough to dissolve the wax crystals.
- c) Samples that are prone to contain particles, such as used oils or crude oils, shall be passed through a 75 µm screen prior to measurement. If these particles are ferromagnetic in nature, a magnet (6.7) should be used instead.

7.2.2 Conditioning of residual fuel oils

7.2.2.1 Place the required number of disposable syringes or sample vials for batch analysis in a sample preheat apparatus (e.g. oven, heating block or bath) held between 60 °C and 65 °C. When manually filling the measuring cells, the Stabinger type viscometer shall be equipped with a hot filling adapter and the injection adapters shall be pre-warmed together with the syringes.

7.2.2.2 Heat the sample in its tightly closed original container in the sample preheat apparatus, held between 60 °C and 65 °C, for 1 h. After heating, the sample shall be sufficiently fluid for easy shaking and stirring.

7.2.2.3 For samples of a very waxy nature or oils of high kinematic viscosity, it may be necessary to increase the heating temperature above 60 °C to achieve proper mixing. The sample should be sufficiently fluid after heating for ease of stirring and shaking.

7.2.2.4 Thoroughly stir the sample with a suitable rod of sufficient length to reach the bottom of the container. Continue stirring until the sample is entirely homogeneous and there is no sludge or wax adhering to the rod.

7.2.2.5 Recap the container tightly and shake vigorously for 1 min to complete the mixing.

7.2.2.6 Immediately thereafter, pour a sufficient amount of the sample into a glass flask to fill the apparatus' sampler system and loosely stopper the flask.

7.2.2.7 Immerse the flask in a heated liquid bath or another equipment which will maintain the sample between 100 °C and 105 °C for 30 min.

Care shall be taken at this step, as vigorous boil-over can occur when opaque liquids which contain high levels of water are heated to high temperatures. Appropriate personal protective equipment should be worn when handling hot materials.

7.2.2.8 Remove the flask from the bath (or other equipment), stopper tightly and shake for 1 min.

7.2.2.9 If the sample is manually introduced into the viscometer, fill the sample into a preheated syringe by using a preheated injection adapter and measure immediately.

7.2.2.10 If a heated sample changer is used, set the vial magazine temperature to be held between 60 °C and 80 °C. Load each sample into a preheated sample vial and insert the vials into the vial magazine. Wait for 10 min to 15 min before starting the measurement.

7.2.2.11 If a heated sample handler is used, load the preheated sample vial or syringe (depending on the model) with the first sample to be tested in the batch and place the sample vial or syringe in the sample handler that is held between 60 °C and 80 °C. Set the temperature of the sample preheat apparatus to between 60 °C and 80 °C and place the other containers in it.

7.2.2.12 Measurement of samples shall be completed within 1 h from completion of the step specified in [7.2.2.8](#).

8 Calibration and verification

8.1 General

The calibration shall be verified periodically using certified reference liquids ([5.4](#)).

Due to the measuring range of the viscosity and temperature, more than one certified reference liquid can be required. If a reference liquid gives no reference value or if the given reference value is not sufficiently precise for one of the two parameters (viscosity or density), (e.g. a density standard without viscosity values), the affected parameter shall be verified with another suitable reference liquid.

Verify the calibration of the temperature measurement periodically by using a reference thermometer ([5.5](#)).

The recommended interval to verify viscosity and density calibration is once a month; for temperature control, once a year.

8.2 Instrument

Ensure that the instrument is leak tight and the measuring cells have been cleaned and dried before verification of the calibration is undertaken.

The verification of the calibration (calibration check measurement) should be carried out according to the instrument manufacturer's instructions.

Calculate an acceptable verification limit in accordance with [Annex A](#). If, despite the correct condition of the instrument, the measured viscosity or density does not lie within the acceptable verification limit 19 out of 20 times, then the viscosity or density cell or both shall be adjusted according to the instrument manufacturer's instructions. Perform a calibration check measurement for verification after the adjustment.

NOTE Measurement values of viscosity and density that do not correspond to the certified values within the limits given are typically attributable to deposits in the measuring cells which are not removed by a routine flushing procedure. Refer to [10.2.7](#) and the manufacturer's instructions for more thorough cleaning methods.

If the measured temperature does not correspond to the certified value in acceptable deviation, i.e. $\pm 0,03$ °C over the range from 15 °C to 100 °C or $\pm 0,05$ °C outside this range, then the instrument shall be adjusted according to the instrument manufacturer's instructions.

9 Apparatus preparation

Ensure that the measuring cells are clean and dry before filling the sample. The displayed density value of air can be used as an indicator.

Set the desired measuring temperature. The Stabinger type viscometer automatically ensures temperature control and temperature equilibration of the sample.

When the test temperature is below the dew point of the ambient air, a suitable air-drying apparatus shall be connected to the air pump inlet of the instrument. When using external compressed air or inert gases, ensure that the dew point is lower than the lowest test temperature which can be expected.

Set the determinability and stability criteria according to the values stated in [Table 1](#).

NOTE RDV (repeat deviation viscosity), RDD (repeat deviation density), temperature stability, viscosity stability, density stability and time settings can be summarized under the term "precision class". Refer to the manufacturer's instructions for details.

Table 1 — Determinability and stability settings

	RDV (Determinability, dynamic viscosity) mPa·s	RDD (Determinability, density) g/cm ³	Temperature stability °C	Viscosity stability %	Density Stability g/cm ³	Time ^b s	Repeats ^c	Equilibration time s
For all materials at all temperatures unless specifically listed in this table ^a	0,001 X	0,000 2	$\pm 0,005$	$\pm 0,07$	0,000 03	60	3	0
Residual fuel oils at 50 °C and 100 °C ^a	0,003 5 X	0,000 3	$\pm 0,010$	$\pm 0,10$	0,000 05	40	3	30
Jet fuel at -20 °C and -40 °C, Scanning procedure ^a	0,001 188 9 X	0,000 113	$\pm 0,005$	$\pm 0,07$	0,000 1	60	0	0

X final determination.

^a Reprinted from ASTM D7042-21a[12].

^b Minimum time during which temperature, viscosity and density shall be within the specified stability criteria.

^c Maximum number of allowed repeat measurements to reach the stated determinability criteria.

10 Procedure

10.1 Measuring procedure

There are three different procedures for determination, that include filling and cleaning, which may be used; details are given in [10.2](#), [10.3](#) and [10.4](#). The fourth procedure for determination, temperature scanning (see [10.5](#)), can be applied with either filling and cleaning procedure specified in [10.2](#), [10.3](#) or [10.4](#).

10.2 Manual filling and cleaning using syringes

10.2.1 Load a sufficient amount of the sample into a syringe and remove any air bubbles. Ensure that for the first filling enough sample (at least 2 ml) is used to fill all measuring cells. If a sufficient amount of the sample is available, it is recommended to fill until the sample is visible in the drain hose. Leave the syringe connected to the instrument during the whole measurement procedure. Typically, a 5 ml syringe entirely filled with sample is enough for a measurement with the viscometer.

10.2.2 Switch on the motor for a short time (5 s to 10 s) to ensure that the measuring cells are pre-wetted. In this way any residues are also absorbed into the sample. By subsequently filling at least a further 0,25 ml of the sample, the sample in the measuring cell is replaced by fresh sample. If there is enough sample available, it is recommended to refill with a further 1 ml. Alternatively, the instrument may be set to perform the pre-wetting automatically before the measurement is started.

10.2.3 Start the first determination of viscosity and density. The instrument should automatically and continuously check the stability of the measured values until the set criteria are met (see [Clause 9](#)). Then refill at least 0,25 ml, but preferably 1 ml of sample for the next determination. The procedure is the same as for pre-wetting the cells (see [10.2.2](#)).

10.2.4 If the difference between the determinations is within the set determinability limits (see [Clause 9](#)), then the value of the last determination shall be reported as valid measured result.

10.2.5 For products not described in [Clause 13](#), it is the responsibility of the user to establish reasonable determinability limits by a series of tests.

10.2.6 If the syringe is empty before a valid determination can be obtained, rinse and dry the measuring cells as described in [10.2.7](#) and repeat from step [10.2.1](#).

10.2.7 Cleaning of the measuring cells

Fill the measuring cells with at least 3 ml of the cleaning solvent ([5.1](#)). Check if the density cell is filled completely by examining the displayed density value. Run the motor for at least 10 s. For poorly soluble samples, extend this time and repeat the procedure. Then rinse the measuring cells with the drying solvent ([5.2](#)) and pass through a stream of dry air or nitrogen ([5.3](#)) until the last trace of solvent is removed. Make sure that the measuring cells are clean and dry by checking if the air density value is lower than 0,002 0 g/cm³. If the value exceeds this limit, repeat the procedure or parts of it.

If more thorough cleaning is necessary, the viscosity measuring cell can additionally be cleaned by manually wiping and brushing the measuring rotors with an appropriate sample solvent. The density oscillator can be cleaned with a suitable cleaning agent. Follow the instructions provided by the instrument manufacturer.

10.3 Manual filling using sample displacement

10.3.1 This procedure should only be used if the samples are mutually soluble. The user shall determine if this procedure is applicable to the class of samples to be measured.

10.3.2 Ensure the sample volume is sufficient for complete displacement of the previous sample. Load the sample into the syringe (typically 25 ml) and remove any air bubbles.

10.3.3 Inject at least 3 ml of the test specimen slowly into the measuring cells to prevent merging of the new and the old sample. Leave the syringe connected to the instrument during the whole measurement procedure.

10.3.4 Switch on the motor for a short time (5 s to 10 s) to ensure that the measuring cells are pre-wetted. In this way, any residues are also absorbed into the sample. Fill the cell with a further 1 ml of sample to replace

the sample in the measuring cell by fresh sample. Alternatively, the instrument may be set to perform the pre-wetting automatically before the measurement is started.

10.3.5 Start the first determination of viscosity and density. The instrument should automatically and continuously check the stability of the measured values until the set criteria are met (see [Clause 9](#)). Then refill at least 2 ml of sample for the next determination. The procedure is the same as for pre-wetting the cells (see [10.3.4](#)).

10.3.6 If the difference between the determinations is within the set determinability limits (see [Clause 9](#)), then the value of the last determination shall be reported as valid measured result.

10.3.7 For products not described in [Clause 13](#), it is the responsibility of the user to establish reasonable determinability limits by a series of tests.

10.3.8 If the syringe is empty before a valid determination can be obtained, rinse and dry the measuring cells as described in [10.2.7](#) and repeat from step [10.3.2](#).

10.3.9 After completing the last determination in a series of measurements, clean the measuring cells using the steps described in [10.2.7](#).

10.4 Automatic filling and cleaning by a sample changer/sample handler

10.4.1 Before starting the measuring procedure, set appropriate filling, cleaning and drying parameters in line with the manufacturer's instructions.

10.4.2 Fill sufficient sample volume into a suitable container for the sample changer or sample handler and place the container into the magazine or holder (depending on the model). If the sample changer, the sample handler or the sample requires it, close the containers with appropriate covers.

10.4.3 Before starting the analysis, ensure there is sufficient cleaning solvent ([5.1](#)) and drying solvent ([5.2](#)) and enough space in the waste vessel for collection of the sample and solvent.

10.4.4 After starting the analysis, the measuring cells are automatically filled and pre-wetted and the first determination of viscosity and density is carried out. The instrument should automatically and continuously check the stability of the measured values until the set criteria are met (see [Clause 9](#)). Then the sample changer or sample handler should refill the sample for the next determination.

10.4.5 If the difference between the determinations is within the set determinability limits (see [Clause 9](#)), then the value of the last determination are given as valid measured result.

10.4.6 For products not described in [Clause 13](#), it is the responsibility of the user to establish reasonable determinability limits by a series of tests.

10.4.7 After the analysis, ensure the cells are clean and dried (typically fully automatically).

10.4.8 If after the automatic cleaning and drying sequence, the air density value still exceeds 0,002 0 g/cm³, perform a manual or automated cleaning of the instrument according to the instructions provided by the instrument manufacturer.

10.5 Procedure for temperature scanning

10.5.1 To determine sample properties over a pre-defined temperature range and with pre-defined temperature intervals, a temperature scanning measurement mode may be set in the apparatus.

10.5.2 Define the temperature range as well as the temperature points for obtaining the measurement data. Neither the boiling point of the sample shall be exceeded nor the freezing point shall be undercut. Enter the temperature range and data reporting temperatures into the instrument either as a table, or by means of defining a start and stop temperature as well as a temperature interval.

10.5.3 When measurements below the dew point of ambient air are performed, ice formation shall be avoided by flushing the measuring cells with dry air or dry inert gas after cell cleaning. Additionally, the filling temperature shall be set well above the dew point of ambient air.

10.5.4 If jet fuel is measured in accordance with the method described in this document, the apparatus shall be connected to a counter cooling system, as described in the instrument manufacturer's instructions. The filling temperature shall be set to 15 °C or higher. Set the test temperatures to -20 °C and -40 °C and perform at least two determinations at each temperature to analyse determinability. For conformance with stated precision on jet fuel in [Table 2](#) and [Table 3](#), set the test stability criteria in accordance with [Clause 9](#).

11 Calculation

11.1 Kinematic viscosity, dynamic viscosity and density

Record the dynamic viscosity, in millipascal seconds, or the kinematic viscosity, in square millimetres per second, or both, to four significant digits and optionally the density to the nearest 0,1 kg/m³.

The calculation of kinematic viscosity is usually performed automatically by the instrument using [Formula \(1\)](#):

$$\nu = 1\,000 \eta / \rho \quad (1)$$

where

ν is the kinematic viscosity, expressed in square millimetres per second (mm²/s);

η is the dynamic viscosity, expressed in millipascal seconds (mPa·s);

ρ is the density, expressed in kilograms per cubic metre (kg/m³).

11.2 Viscosity index

If kinematic viscosity values have been determined at 40 °C and 100 °C, the Viscosity Index (VI) may be calculated according to the test method specified in ASTM D2270^[8].

11.3 Density extrapolation

If density values are known from the same sample at 40 °C and 100 °C, density values at other temperatures may be calculated by linear extrapolation. This is only permissible within a temperature range at which no phase transition occurs. It is the responsibility of the user of this document to evaluate the applicability of this calculation to the respective sample.

12 Expression of results

Express the dynamic, η , or kinematic, ν , viscosity, or both, to four significant digits, optionally the density, ρ , to the nearest 0,1 kg/m³, together with the test temperature to the nearest 0,01 °C.

13 Precision

13.1 Repeatability, r

The limiting value for the difference between two independent results obtained in the normal and correct operation of the same method, for test material considered to be the same, within a short interval of time, under the same test conditions, that is expected to be exceeded with a probability of 5 % due to random variation, is given in [Table 2](#).

Table 2 — Repeatability (95 %)

Material	Temperature °C	Density g/cm ³	Dynamic viscosity mPa·s	Kinematic viscosity mm ² /s
Base oils ^a	15	0,000 46	N/A	N/A
Base oils ^a	40	0,000 3	0,001 01X	0,000 94X
Base oils ^a	100	0,000 33	0,000 351 6 (X+5)	0,000 347 3 (X+5)
Formulated oils ^b	40	0,000 3	0,006 279X	0,006 (X+10,6)
Formulated oils ^b	100	0,000 2	0,012 09X ^{0,5}	0,002 068(X+7,77)
Jet fuels ^c	−20	0,001	0,064 77	0,085 6
Jet fuels, scanning procedure ^d	−20 ^e	0,001 97X	0,005 978X	0,007 074X
Jet fuels, scanning procedure ^d	−40	0,001 97X	0,004 34X	0,005 261X
Residual fuel oils ^f	50	0,000 98	0,094 69X	0,090 93X
Residual fuel oils ^f	100	0,002 49	0,051 7X	0,053 49X
Middle distillate fuels, fatty acid methyl ester (FAME) fuels and mixtures of these ^g	40	0,000 6X 0,000 278 4	0,001 1X+0,005 4	−0,000 3X+0,010 5

X average of results being compared.

^a Base oil precision values were determined by statistical evaluation of interlaboratory results. Refer to [13.4](#) for details^[19].

^b Formulated oil precision values were determined by statistical evaluation of interlaboratory results. Refer to [13.4](#) for details^[15].

^c Jet fuel precision values at −20 °C were determined by statistical evaluation of interlaboratory results. Refer to [13.4](#) for details^[17].

^d Jet fuel precision values at −20 °C and −40 °C when employing the temperature scanning procedure, were determined by statistical evaluation of interlaboratory results. Refer to [13.4](#) for details^[20].

^e This repeatability is currently not referenced in specification ASTM D1655–23a. Use the precision statement for jet fuel at −20 °C without scanning.

^f Residual fuel oil precision values were determined by statistical evaluation of interlaboratory results. Refer to [13.4](#) for details^[18].

^g These precision values were determined by statistical evaluation of interlaboratory results. Refer to [13.4](#) for details^[3].

13.2 Reproducibility, R

The limiting value for the difference between two independent results obtained in the normal and correct operation of the same method, for test material considered to be the same, under different test conditions, that is expected to be exceeded with a probability of 5 % due to random variation, is given in [Table 3](#).

Table 3 — Reproducibility (95 %)

Material	Temperature °C	Density g/cm ³	Dynamic viscosity mPa·s	Kinematic Viscosity mm ² /s
Base oils ^a	15	0,001 77	N/A	N/A
Base oils ^a	40	0,001 47	0,005 40X	0,005 84X
Base oils ^a	100	0,001 31	0,002 563 (X+5)	0,002 889 (X+5)
Formulated oils ^b	40	0,001 3	0,005 076X ^{1,2}	0,010 87 (X+10,6)
Formulated oils ^b	100	0,001 2	0,008 223X ^{1,028 8}	0,006 346 (X+7,77)
Jet fuels ^c	−20	0,002 7	0,108 5	0,148 5
Jet fuels, scanning procedure ^d	−20 ^e and −40	0,002 03X	0,021 2X	0,021 2X
Residual fuel oils ^f	50	0,001 44	0,101 2X	0,102 9X
Residual fuel oils ^f	100	0,004 99	0,081 33X	0,071 86X
Middle distillate fuels, fatty acid methyl ester (FAME) fuels and mixtures of these ^g	40	0,001X+0,000 725 7	0,005 4X+0,026	0,005X+0,034 6

X average of results being compared

^a Base oil precision values were determined by statistical evaluation of interlaboratory results. Refer to [13.4](#) for details^[19].

^b Formulated oil precision values were determined by statistical evaluation of interlaboratory results. Refer to [13.4](#) for details^[15].

^c Jet fuel precision values at −20 °C were determined by statistical evaluation of interlaboratory results. The reproducibility estimate from the interlaboratory study has 18 degrees of freedom. This falls below the minimum requirement of 30 as defined by practice ASTM D6300. Thus, the actual reproducibility may significantly differ from these estimates. Refer to [13.4](#) for details^[17].

^d Jet fuel precision values at −20 °C and −40 °C when employing the temperature scanning procedure were determined by statistical evaluation of interlaboratory results. Refer to [13.4](#) for details^[20].

^e This repeatability is currently not referenced in specification ASTM D1655–23a. Use the precision statement for jet fuel at −20 °C without scanning.

^f Residual fuel oil precision values were determined by statistical evaluation of interlaboratory results. Refer to [13.4](#) for details^[18].

^g These precision values were determined by statistical evaluation of interlaboratory results. Refer to [13.4](#) for details^[3].

13.3 Bias

13.3.1 General

NOTE This subclause has been reprinted and modified from ASTM D7042-21a^[12].

During the interlaboratory study samples of middle distillate fuels, fatty acid methyl ester (FAME) fuels and mixtures of these were tested according to ISO 3104 and in line with this document. Based on statistical analysis, no significant bias between the two test methods was found^[3].

For other sample groups, to evaluate the relative bias the samples were tested according to ASTM D7042 and with manual kinematic viscometers according to test method ASTM D445. For determination of the density bias, base oil samples were analysed with digital density meters according to test method ASTM D4052. Both test methods were carried out in the same laboratories as the ASTM D7042 measurements.

All suggested relative bias correction formulae to manual ASTM D445/ISO 3104 kinematic viscosity are summarized in [Table 4](#).

13.3.2 Degree of agreement between results by test method ASTM D7042 and test method ASTM D445

13.3.2.1 The same materials have been measured with test method ASTM D7042 and test method ASTM D445. The obtained data has been assessed in accordance with the procedures described in practice ASTM D6708 and provided:

13.3.2.2 No bias to the test methods specified in ASTM D445 and ASTM D7042 was found to exist for base oils.

13.3.2.3 For formulated oils, the following bias correction was suggested according to RR:D02-1741^[15]:

$$Y_{e40} = 0,996 X_{40} \quad (2)$$

$$Y_{e100} = X_{100} - 0,023538 \quad (3)$$

where

Y_{e40} is the predicted ASTM D445 result at 40 °C. This result would have been obtained if the same sample had been measured with test method ASTM D445 (mm²/s);

Y_{e100} is the predicted ASTM D445 result at 100 °C. This result would have been obtained if the same sample had been measured with test method ASTM D445 (mm²/s);

X_{40} is the result from the test method specified in ASTM D7042 at 40 °C (mm²/s);

X_{100} is the result from the test method specified in ASTM D7042 at 100 °C (mm²/s).

If the kinematic viscosity obtained from the test method specified in ASTM D7042 is bias-corrected according to [Formula \(2\)](#) or [Formula \(3\)](#), the result may be considered as practically equivalent to the results obtained with the test method specified in ASTM D445 for the types of material and within the property ranges examined. After bias-correction, no sample-specific bias, as described in practice ASTM D6708, was found in the materials investigated.

For the sample types and property ranges under study, bias-corrected data from test methods ASTM D7042 and data from ASTM D445 measurements is expected to differ by more than the following between methods reproducibility, R_{xy} , as outlined in practice ASTM D6708, approximately 5 % of the time. At 40 mm²/s the R_{xy} was 0,521 56 mm²/s at 40 °C, and at 10 mm²/s the R_{xy} was 0,088 19 mm²/s at 100 °C.

To demonstrate that the viscosity modifier (polymeric additive) type did not affect the bias between the methods, additional data was requested. A pilot study confirmed that regardless of the type of polymeric additive, applying the previously established bias correction is appropriate^[16].

13.3.2.4 For jet fuel at –20 °C, the following bias correction was suggested according to RR:D02-1750^[17]:

If the kinematic viscosity obtained from test method ASTM D7042 is bias-corrected according to [Formula \(4\)](#), the result may be considered as practically equivalent to the results obtained with test method ASTM D445 for the types of material and within the property ranges examined. After bias-correction, no sample-specific bias, as described in the practice specified in ASTM D6708, was found in the materials investigated.

$$Y_e = X - 0,013373 \quad (4)$$

where

Y_e is the predicted ASTM D445 result at –20 °C. This result would have been obtained if the same sample had been measured with test method ASTM D445 (mm²/s);

X is the result from the test method specified in ASTM D7042 at –20 °C (mm²/s).

For the sample types and property ranges under study, bias-corrected data from test methods ASTM D7042 and data from ASTM D445 measurements is expected to differ by more than the following between methods reproducibility, R_{xy} , as outlined in practice ASTM D6708, approximately 5 % of the time. $R_{xy} = 0,162 \text{ mm}^2/\text{s}$ at $-20 \text{ }^\circ\text{C}$.

13.3.2.5 For residual fuel oils at $50 \text{ }^\circ\text{C}$, according to RR:D02-1837^[18] no bias correction is necessary and no sample specific biases can be identified. For residual fuel oil at $100 \text{ }^\circ\text{C}$, RR:D02-1837 suggests a bias correction of $0,251 \text{ mm}^2/\text{s}$, but no sample specific biases were found.

$$Y_e = X + 0,251 \quad (5)$$

where

Y_e is the predicted ASTM D445 result at $50 \text{ }^\circ\text{C}$. This result would have been obtained if the same sample had been measured with test method ASTM D445 (mm^2/s);

X is the result from the test method specified in ASTM D7042 at $50 \text{ }^\circ\text{C}$ (mm^2/s).

For the sample types and property ranges under study, bias-corrected data from test methods ASTM D7042 and data from ASTM D445 measurements is expected to differ by more than the following between methods reproducibility, R_{xy} , as outlined in practice ASTM D6708, approximately 5 % of the time:

$$R_{xy} = (0,5 R_x^2 + 0,5 R_y^2)^{0,5} \quad (6)$$

where

R_{xy} is the between methods reproducibility;

R_x is the reproducibility of ASTM D7042;

R_y is the reproducibility of ASTM D445.

Table 4 — Suggested relative bias correction to manual ASTM D445/ISO 3104 kinematic viscosity

Material	Temperature $^\circ\text{C}$	Relative bias correction mm^2/s	Bias-corrected X (predicted Y) = $mX+b$ mm^2/s
Base oils ^a	40 and 100	none	$m = 1, b = 0$
Formulated oils ^a	40	$0,996X$	$m = 0,996, b = 0$
Formulated oils ^a	100	$X-0,023\ 538$	$m = 1, b = -0,023\ 538$
Jet fuels ^a	-20	$X-0,013\ 373$	$m = 1, b = -0,013\ 373$
Jet fuels, Scanning procedure ^a	-20 and -40	N/A	N/A
Residual fuel oils ^a	50	none	$m = 1, b = 0$
Residual fuel oils ^a	100	$1X+0,251$	$m = 1, b = 0,251$
Middle Distillate Fuels, Fatty Acid Methyl Ester (FAME) Fuels and mixtures of these ^b	40	none	$m = 1, b = 0$
^a Reprinted from ASTM D7042-21a ^[12] .			
^b Refer to 13.3 for details.			

13.4 Interlaboratory study

NOTE This subclause has been reprinted and modified from ASTM D7042-21a^[12].

The precision statement for Middle Distillate Fuels, Fatty Acid Methyl Ester (FAME) Fuels and mixtures of these was developed by statistical evaluation of the results of a CEN interlaboratory study in accordance

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with ISO 4259-1^[1]. For other sample groups, interlaboratory studies were performed following the practices specified in ASTM D6300 and ASTM D6708. Details are given in [Table 5](#).

Table 5 — Interlaboratory study

Material	Temperature °C	Samples	Laboratories	Dynamic viscosity range mPa·s	Density range g/cm ³	Kinematic viscosity range mm ² /s	First issued in year
Base oils ^a	15	10	12		0,82 to 0,92		2003
Base oils ^a	40			2,05 to 456		2,48 to 514	
Base oils ^a	100			0,83 to 31,6		1,06 to 39,6	
Formulated oils ^b	40	10	19	34 to 411	0,829 89 to 0,873 00 ^g	40,164 to 150,71 ^h	2012
Formulated oils ^b	100		18	5,24 to 39,2	0,791 92 to 0,835 12 ⁱ	6,468 2 to 48,292	
Jet fuels ^c	-20	12	13	3,170 5 to 6,748 9	0,786 72 to 0,859 98	3,808 7 to 7,982 4	2012
Jet fuels, scanning procedure ^d	-20	15	10	2,754 65 to 5,799 55	0,783 13 to 0,853 31	3,383 7 to 6,784 1	2019
Jet fuels, scanning procedure ^d	-40			5,259 4 to 14,002	0,797 44 to 0,867 96	6,350 75 to 16,170 5	2019
Residual fuel oils ^e	50	10	10	25,31 to 2 212	0,917 3 to 0,993 7	27,6 to 2 230	2016
Residual fuel oils ^e	100			5,493 to 109,1	0,883 1 to 0,961 1	6,202 to 108,1	
Middle distillate fuels, fatty acid methyl ester (FAME) fuels and mixtures of these ^f	40	12	21			2,61 to 5,50	2014

^a Base oil samples without additive package. Linear extrapolation of density results at 40 °C and 100 °C gave density values at 15 °C. The samples were tested as duplicates, measured within a time interval of typically less than 10 min following the standard procedure depicted in [Clause 10](#). Precision data on base oils was obtained using manual sample introduction exclusively^[19].

^b Commercially available samples, e.g. motor oils, hydraulic oils, and synthetic gear oils^[15].

^c Jet fuel samples Jet-A, Jet-A1, JP8, SPK, SPK blend, and N2B viscosity standard^[17].

^d Jet fuel samples conforming to ASTM D1655^[7], ASTM D7566^[13] or DEF STAN 91-091. Performed according to practices ASTM D6300^[10] and ASTM D7915^[14].

^e Residual fuel samples conforming to Grades No. 5 or 6 as specified in ASTM D396^[5] and/or RMG and RMK grades specified in ISO 8217^[2].

^f Single FAME types (e.g. palm-kernel- and rape-seed-based), blends of methyl esters, different middle distillates and a mix (50/50) of paraffinic diesel fuel (GTL) and arctic diesel fuel MK1^[3].

^g Test conducted in 20 laboratories.

^h Test conducted with 9 formulated oils.

ⁱ Test conducted in 19 laboratories.

14 Test report

The test report shall contain at least the following information:

- reference to this document, i.e. ISO 23581:2024;
- type and complete identification of the product tested;