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Petroleum products — Determination of knock characteristics of motor and aviation fuels — Motor method

*Produits pétroliers — Détermination des caractéristiques antidétonantes
des carburants pour moteurs automobile et aviation — Méthode moteur*



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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.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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

ISO 5163 was prepared by Technical Committee ISO/TC 28, *Petroleum products and lubricants*.

This third edition cancels and replaces the second edition (ISO 5163:1990), which has been technically revised.

Introduction

The purpose of this International Standard is to accord ISO status to a test procedure that is already used in a standardized form all over the world. The procedure in question is published by ASTM International as Standard Test Method D 2700-01a.

By publishing this International Standard, ISO recognizes that this method is used in its original text in many member countries and that the standard equipment and many of the accessories and materials required for the method are obtainable only from specific manufacturers or suppliers. To carry out the procedure requires reference to six annexes and three appendices of ASTM D 2700-01a, contained in the Annual Book of ASTM Standards, Section 5¹⁾. The annexes detail the specific equipment and instrumentation required, the critical component settings and adjustments, and include the working tables of referenced settings. The appendices provide background and additional insight about auxiliary equipment, operational techniques and the concepts relative to proper maintenance of the engine and instrumentation items.

The accumulated motor and aviation-type fuel data relating to knock characteristics determined in many countries has, for many years, been based on the use of the CFR engine²⁾ and the ASTM octane test methods. Accepted worldwide, petroleum industry octane number requirements for motor and aviation-type fuels are defined by the motor method and associated CFR F-2 Octane Rating Unit, which emphasizes the need for this method and test equipment to be standardized. The initiation of studies to use a different engine for ISO purposes has therefore been considered an unnecessary duplication of effort.

It is further recognized that this method for rating motor and aviation-type fuels, which does include metric operating conditions, is nevertheless an exceptional case in that the CFR engine is manufactured to inch dimensions and requires numerous settings and adjustments to inch dimensions. Application of metrication to these dimensions and tolerances can only be accomplished by strict numerical conversion which would not reflect proper metric engineering practice. Attempts to utilize metric measurement instruments for checking component dimensions to the numerically converted metric values would only introduce an additional source of test variability.

For these reasons, it has been considered desirable by ISO Technical Committee 28, *Petroleum products and lubricants*, to adopt the ASTM D 2700 standard rewritten to comply with the ISO Directives, Part 2, *Rules for the structure and drafting of International Standards*. However, this International Standard refers to annexes and appendices of ASTM D 2700 without change because of their extensive detail. These annexes and appendices are not included in this International Standard because they are published in the Annual Book of ASTM Standards, Section 5.

1) Copies may be purchased directly from the publisher, ASTM International, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA, telephone: +1 610-832-9585, fax: +1 610-832-9555, e-mail: service@astm.org, website: www.astm.org.

2) The sole manufacturer of the Model CFR F-2 Octane Rating Unit is Waukesha Engine, Dresser, Inc., 1000 West St. Paul Avenue, Waukesha, WI 53188, USA.

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Petroleum products — Determination of knock characteristics of motor and aviation fuels — Motor method

WARNING — The use of this International Standard may involve hazardous materials, operations and equipment. This International Standard does not purport to address all of the safety problems associated with its use. It is the responsibility of the user of this International Standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.

1 Scope

This International Standard establishes the rating of liquid spark-ignition engine fuel in terms of an arbitrary scale of octane numbers using a standard single-cylinder, four-stroke cycle, variable-compression ratio, carburetted, CFR engine operated at constant speed. Motor octane number (MON) provides a measure of the knock characteristics of motor fuels in automotive engines under severe conditions of operation. The motor octane number provides a measure of the knock characteristics of aviation fuels in aviation piston engines, by using an equation to correlate to aviation-method octane number or performance number (lean-mixture aviation rating).

This International Standard is applicable for the entire scale range from 0 MON to 120 MON, but the working range is 40 MON to 120 MON. Typical motor fuel testing is in the range of 80 MON to 90 MON. Typical aviation fuel testing is in the range of 98 MON to 102 MON.

This International Standard can be used for oxygenate-containing fuels containing up to 4,0 % (*m/m*) oxygen.

Certain gases and fumes, such as halogenated refrigerants used in air-conditioning equipment that can be present in the area where the CFR engine is located, may have a measurable effect on the MON rating. Electrical power transient voltage or frequency surges or distortion can affect MON ratings.

NOTE 1 This International Standard specifies operating conditions in SI units but engine measurements are specified in inch-pound units because these are the units used in the manufacture of the equipment, and thus some references in this International Standard include these units in parenthesis.

NOTE 2 For the purposes of this International Standard, the expressions “% (*m/m*)” and “% (*V/V*)” are used to represent the mass and volume fractions of a material, respectively.

2 Normative references

The following referenced documents are indispensable for the application 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 3170:2004, *Petroleum liquids — Manual sampling*

ISO 3171:1988, *Petroleum liquids — Automatic pipeline sampling*

ISO 3696:1987, *Water for analytical laboratory use — Specification and test methods*

ISO 4787:1984, *Laboratory glassware — Volumetric glassware — Methods for use and testing of capacity*

ASTM D 2700-01a, *Standard Test Method for Motor Octane Number of Spark-Ignition Engine Fuel*

3 Terms and definitions

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

**3.1
check fuel**
fuel of selected characteristics that has a MON assigned reference value determined by round-robin testing by multiple engines in different locations

**3.2
cylinder height**
relative vertical position of the CFR engine cylinder with respect to the piston at top dead centre (t.d.c.) or the top machined surface of the crankcase

**3.3
dial indicator reading**
numerical indication of cylinder height, indexed to a basic setting when the engine is motored with the compression ratio set to produce a specified compression pressure

NOTE The dial indicator reading is expressed in thousandths of an inch.

**3.4
digital counter reading**
numerical indication of cylinder height, indexed to a basic setting when the engine is motored with the compression ratio set to produce a specified compression pressure

**3.5
detonation meter**
knock signal conditioning instrumentation that accepts the electrical signal from the detonation pickup and produces an output signal for display

**3.6
detonation pickup**
magnetostrictive-type transducer that threads into the engine cylinder to sense combustion-chamber pressure and provide an electrical signal proportional to the rate-of-change of that cylinder pressure

**3.7
firing**
engine operation with fuel and ignition

**3.8
fuel-air ratio for maximum knock intensity**
proportion of fuel to air that produces the highest knock intensity for each fuel

**3.9
guide table**
tabulation of the specific relationship between cylinder height and octane number for the CFR engine operated at standard knock intensity and a specified barometric pressure

**3.10
knock**
abnormal combustion, often producing an audible sound, caused by auto-ignition of the air-fuel mixture

**3.11
knock intensity**
measure of engine knock

3.12**knockmeter**

indicating meter with a 0-to-100 division scale that displays the knock intensity signal from the detonation meter

3.13**lean mixture aviation rating**

indication of the knock resistance for a fuel operating in an aviation piston engine under lean fuel-air ratio conditions

3.14**motoring**

engine operation without fuel and with the ignition off

3.15**motor octane number****MON**

numerical rating of knock resistance for a fuel obtained by comparing its knock intensity with that of primary reference fuels of known motor octane number when tested in a standardized CFR engine operating under conditions specified in this International Standard

3.16**oxygenate**

oxygen-containing organic compound, such as various alcohols or ethers, used as a fuel or fuel supplement

3.17**primary reference fuel****PRF**

2,2,4-trimethylpentane (isooctane), heptane, volumetrically proportioned mixtures of isooctane with heptane, or blends of tetraethyl lead in isooctane, which define the octane number scale

3.18**spread**

sensitivity of the detonation meter, expressed in knockmeter divisions per octane number

3.19**toluene standardization fuel blend****TSF blend**

volumetrically proportioned blend of two or more of the following; reference fuel grade toluene, heptane, and isooctane, that have MON accepted reference values and specified rating tolerances

4 Principle

A sample fuel, operating in a CFR engine at the fuel-air ratio that maximizes its knock, is compared to primary reference fuel blends to determine that blend which, when operated at the fuel-air ratio that maximizes its knock, would result in both fuels producing the same standard knock intensity when tested at the same engine compression ratio. The volumetric composition of the primary reference fuel blend defines both its octane number and that of the sample fuel.

5 Reagents and reference materials**5.1 Cylinder-jacket coolant**, consisting of water conforming to grade 3 of ISO 3696:1987.

Water shall be used in the cylinder jacket for laboratory locations where the resultant boiling temperature is $100\text{ °C} \pm 2\text{ °C}$. Water with commercial glycol-based antifreeze added in sufficient quantity to meet the boiling temperature requirement shall be used when laboratory altitude dictates.

A commercial multi-functional water treatment material should be used in the coolant to minimize corrosion and mineral scale that can alter heat transfer and rating results.

5.2 Carburettor coolant, if required (see 8.30), consisting of water or a water-antifreeze mixture, chilled sufficiently to prevent fuel bubbling, but neither colder than 0,6 °C nor warmer than 10 °C.

5.3 Engine crankcase-lubricating oil, comprising an SAE 30 viscosity grade oil meeting service classification SF/CD or SG/CE.

It shall contain a detergent additive and have a kinematic viscosity of 9,3 mm²/s to 12,5 mm²/s at 100 °C and a viscosity index of not less than 85. Oils containing viscosity index improvers shall not be used. Multi-grade lubricating oils shall not be used.

5.4 2,2,4-trimethylpentane (isooctane) primary reference fuel, of minimum purity 99,75 % (V/V), containing no more than 0,10 % (V/V) heptane and no more than 0,5 mg/l lead. This material shall be designated as 100 MON.

NOTE Certified reference materials, such as CRM IRMM-442 and NIST SRM 1816a, are commercially available.

5.5 Heptane primary reference fuel, of minimum purity 99,75 % (V/V), containing no more than 0,10 % (V/V) isooctane and no more than 0,5 mg/l lead. This material shall be designated as 0 MON.

NOTE Certified reference materials, such as CRM IRMM-441 and NIST SRM 1815a, are commercially available.

5.6 80-octane primary reference fuel blend, prepared using reference fuel grade isooctane (5.4) and heptane (5.5); this blend shall contain 80 % (V/V) ± 0,1 % (V/V) isooctane.

NOTE ASTM D 2700-01a, Annex A5 (Reference Fuel Blending Tables), provides information for preparation of primary reference fuel blends to specific MON values.

5.7 Tetraethyl lead, dilute, (TEL dilute volume basis), consisting of a solution of aviation-mix tetraethyl lead antiknock compound in a hydrocarbon diluent of 70 % (V/V) xylene and 30 % (V/V) heptane.

The antiknock compound shall contain 18,23 % (m/m) ± 0,05 % (m/m) tetraethyl lead and have a relative density at 15,6 °C/15,6 °C of 0,957 to 0,967.

NOTE The typical composition of the compound, excluding the tetraethyl lead, is as follows:

Ethylene dibromide (scavenger):	10,6 % (m/m)
Diluent:	
xylene	52,5 % (m/m)
heptane	17,8 % (m/m)
dye, antioxidant and inerts	0,87 % (m/m)

5.8 Primary reference fuel blends for ratings over 100 MON, prepared by adding dilute tetraethyl lead (5.7), in specified millilitre quantities, to a 400 ml volume of isooctane (5.4).

These blends define the MON scale above 100.

NOTE ASTM D 2700-01a, Annex A5 (Reference Fuel Blending Tables), provides the MON values for blends of tetraethyl lead in isooctane.

5.9 Methylbenzene (toluene), reference fuel grade, with a minimum purity of 99,5 % (V/V) as determined by chromatographic analysis, a peroxide number not exceeding 5 mg/kg and a water content not exceeding 200 mg/kg.

Antioxidant treatment should be added by the supplier at a rate suitable for long-term stability, as empirically determined with the assistance of the antioxidant supplier.

5.10 Check fuels, consisting of in-house typical spark-ignition engine fuels having MON accepted reference values, low volatility and good long-term stability.

6 Apparatus

6.1 Test engine assembly, a CFR F-2 octane rating unit consisting of a single-cylinder engine composed of a standard crankcase, a variable-compression-ratio cylinder — clamping sleeve assembly, thermal-siphon recirculating jacket cooling system, multiple-fuel-bowl system with selector valving to deliver fuel through a single-jet passage and carburettor venturi, an intake mixture manifold with mixture heater, an intake air system with controlled temperature and humidity equipment, electrical controls, and a suitable exhaust pipe.

The engine shall be connected by a belt to a special electric power-absorption motor that acts as a motor driver to start the engine and as a means to absorb power at constant speed when combustion is occurring (engine firing). See ASTM D 2700-01a, Annex A2 (Engine Equipment Description and Specifications), for all critical, non-critical and equivalent engine equipment, which shall apply for this International Standard.

6.2 Instrumentation, consisting of electronic-detonation metering instrumentation, including a detonation pickup and knockmeter to measure and display the intensity of combustion knock, as well as conventional thermometry, gauges and general-purpose meters. See ASTM D 2700-01a, Annex A3 (Instrumentation Description and Specifications), for all critical, non-critical and equivalent instrumentation, which shall apply for this International Standard.

NOTE Engine equipment and instrumentation are available from the single-source manufacturer, Waukesha Engine, Dresser, Inc., 1000 West St. Paul Avenue, Waukesha, WI 53188, USA. Waukesha Engine also has authorized sales and service organizations in selected geographic areas. This information is given for the convenience of users of this International Standard but does not constitute an endorsement by ISO of this product.

6.3 Reference and standardization fuel dispensing equipment, consisting of calibrated burettes or volumetric ware having a capacity of 200 ml to 500 ml and a maximum volumetric tolerance of $\pm 0,2$ %.

Calibration shall be verified in accordance with ISO 4787. Burettes shall be outfitted with a delivery valve and delivery tip to accurately control dispensed volumes. The delivery tip shall be of such size and design that shut-off tip discharge does not exceed 0,5 ml. The rate of delivery from the dispensing system shall not exceed 400 ml/min.

6.4 Tetraethyl lead (TEL) dispensing equipment, consisting of a calibrated burette, pipette assembly, or other liquid-dispensing apparatus, having a capacity not exceeding 4,0 ml, and a critically controlled tolerance for dispensing dilute TEL into 400 ml batches of isooctane.

Calibration shall be verified in accordance with ISO 4787.

NOTE ASTM D 2700-01a, Appendix X1 (Reference Fuel Blending Apparatus and Procedures), provides additional information for application of this International Standard.

6.5 Special maintenance tools, consisting of a number of specialty tools and measuring instruments available for easy, convenient and effective maintenance of the engine and testing equipment.

NOTE Lists and descriptions of these tools and instruments are available from the manufacturers of the engine equipment and those organizations offering engineering and service support for this International Standard.

7 Sampling and sample preparation

7.1 Obtain samples in accordance with ISO 3170, ISO 3171 or an equivalent national standard.

7.2 Cool samples to 2 °C to 10 °C in the container in which they are received and before the container is opened.

7.3 Minimize the sample's exposure to light before pouring it into the engine carburettor fuel bowl, because of possible sensitivity to light that can affect fuel characteristics.

8 Basic engine and instrument settings and standard operating conditions

8.1 Installation of engine equipment and instrumentation

Locate the octane test engine in an area where it will not be affected by certain gases and fumes that may have a measurable effect on the MON test result (see Clause 1).

Installation of the engine and instrumentation requires placement of the engine on a suitable foundation and hook-up of all utilities. Engineering and technical support for this function is required, and the user shall be responsible for complying with all local and national codes and installation requirements. Proper operation of the test engine requires assembly of a number of engine components and adjustment of a series of engine variables to prescribed specifications. Some of these settings are established by component specifications, others are established at the time of engine assembly or after overhaul and still others are engine-running conditions that shall be observed and/or determined by operator adjustment during the testing process.

8.2 Engine speed

The engine speed shall be $900 \text{ r/min} \pm 9 \text{ r/min}$ when the engine is operating with combustion with a maximum variation of 9 r/min occurring during a rating.

Engine speed when combustion is occurring shall not be more than 3 r/min greater than for motoring without combustion.

8.3 Valve timing

The four-stroke cycle engine uses two crankshaft revolutions for each combustion cycle. The two critical events are those that occur near top-dead-centre (t.d.c.), i.e. intake valve opening and exhaust valve closing. Intake valve opening shall occur $10,0^\circ \pm 2,5^\circ$ after t.d.c., with closing at 34° after-bottom-dead-centre (a.b.d.c.) on one revolution of the crankshaft and flywheel. Exhaust valve opening shall occur 40° before-bottom-dead-centre (b.b.d.c.) on the second revolution of the crankshaft and flywheel with closing at $15,0^\circ \pm 2,5^\circ$ a.t.d.c. on the next revolution of the crankshaft and flywheel. See ASTM D 2700-01a, Annex A4 (Apparatus Assembly and Setting Instructions), for the procedures for crankshaft timing that shall apply for this International Standard.

8.4 Valve lift

Intake and exhaust cam lobe contours, whilst different in shape, shall have a contour rise of $6,248 \text{ mm}$ to $6,350 \text{ mm}$ ($0,246 \text{ in}$ to $0,250 \text{ in}$) from the base circle to the top of the lobe so that the resulting valve lift shall be $6,045 \text{ mm} \pm 0,050 \text{ mm}$ ($0,238 \text{ in} \pm 0,002 \text{ in}$). See ASTM D 2700-01a, Annex A4 (Apparatus Assembly and Setting Instructions), for the procedures for measuring valve lift that shall apply for this International Standard.

8.5 Intake valve shroud

The 180° shroud directs the incoming fuel-air mixture and increases its turbulence in the combustion chamber. A pin in the valve stem mates with a slot in the valve guide to prevent valve rotation. Assembly of the valve in the cylinder requires that the stem pin alignment positions the valve so the shroud is toward the spark plug side of the combustion chamber.

8.6 Direction of engine rotation

The crankshaft, when observed from the front of the engine, rotates in a clockwise direction.

8.7 Carburettor venturi

Select the carburettor venturi in accordance with Table 1 appropriate for the typical barometric pressure that prevails at the location where the engine is installed and operated.

Table 1 — Carburettor venturi size for laboratory elevation and barometric pressure

Altitude at engine location m	Venturi throat size cm (in)	Barometric pressure range kPa (in Hg)
Sea level to 500	1,43 (9/16)	105,0 to 94,8 (31,0 to 28,0)
500 to 1 000	1,51 (19/32)	98,2 to 88,0 (29,0 to 26,0)
Higher than 1 000	1,90 (3/4)	91,4 (27,0) and less

When the altitude is close to that where venturi size changes, select whichever venturi size produces a minimum bias for the toluene standardization fuel (TSF) blend MON ratings.

8.8 Valve clearances

With the engine cold prior to being operated, set the clearance between each valve stem and valve rocker half-ball to the following approximate measurements upon assembly, which will typically provide the controlling engine running and hot clearance:

- intake valve 0,102 mm (0,004 in);
- exhaust valve 0,356 mm (0,014 in).

These clearances should ensure that both valves have sufficient clearance to cause valve seating during engine warm-up. The adjustable-length valve push rods shall be set so that the valve rocker adjusting screws have adequate travel to permit the final clearance setting. Engine running and hot clearance for both intake and exhaust valves shall be set to 0,200 mm \pm 0,025 mm (0,008 in \pm 0,001 in) measured under standard operating conditions with the engine running at equilibrium conditions on a 90 MON primary reference fuel.

8.9 Oil pressure

Oil pressure shall be 172 kPa to 207 kPa.

8.10 Oil temperature

Oil temperature shall be 57 °C \pm 8 °C.

8.11 Cylinder jacket coolant temperature

Cylinder jacket coolant temperature shall be 100 °C \pm 1,5 °C, but shall not vary by more than \pm 0,5 °C during a rating.

8.12 Intake air temperature

Intake air temperature shall be 38,0 °C \pm 2,8 °C.

8.13 Intake mixture temperature

Set the temperature to 149 °C \pm 1 °C unless mixture-temperature tuning is utilized to qualify the engine as fit-for-use based on the MON value of the appropriate toluene standardization fuel (TSF) blend. When the mixture temperature is tuned, the selected temperature shall be between 141 °C and 163 °C. Furthermore, the temperature selected to provide the MON of the appropriate TSF blend shall be used during that operating period for all ratings in the applicable MON range for that TSF blend. The intake mixture temperature variation during any rating (tuned or untuned) shall not exceed 1 °C.

8.14 Intake air humidity

The water content of the air shall be between 0,003 56 kg per kilogram of dry air and 0,007 12 kg per kilogram of dry air.

8.15 Cylinder jacket coolant level

The coolant level when the engine is running and hot shall be within ± 10 mm of the "LEVEL HOT" mark on the coolant condenser.

NOTE With the engine cold prior to being operated, treated coolant added to the cooling condenser/cylinder jacket to a level just observable in the bottom of the condenser sight glass will typically provide the controlling engine running and hot operating level.

8.16 Engine crankcase lubricating oil level

The controlling engine running and hot operating level of the oil in the crankcase shall be approximately mid-position in the crankcase sight glass.

NOTE With the engine cold prior to being operated, oil added to the crankcase so that the level is near the top of the sight glass will typically provide this condition.

8.17 Crankcase internal pressure

The pressure shall be less than 0 (a vacuum), and typically from 25 mm to 150 mm of water less than atmospheric pressure, as measured by a gauge or manometer connected to an opening to the inside of the crankcase through a snubber orifice to minimize pulsation. Vacuum shall not exceed 255 mm of water.

8.18 Exhaust back-pressure

The static pressure shall be as low as possible, but shall not create a vacuum nor exceed 255 mm of water differential in excess of atmospheric pressure, as measured by a gauge or manometer connected to an opening in the exhaust surge tank or main exhaust stack through a snubber orifice to minimize pulsations.

8.19 Exhaust and crankcase breather system resonance

The exhaust and crankcase breather piping systems shall have internal volumes and be of such length that gas resonance does not result.

NOTE ASTM D 2700-01a, Appendix X2 (Operating Techniques — Adjustment of Variables), provides a suitable procedure to determine if resonance exists in the application of this International Standard.

8.20 Belt tension

The belts connecting the flywheel to the absorption motor shall be tightened, after initial break-in, so that with the engine stopped, a 2,25 kg mass suspended from one belt halfway between the flywheel and the motor pulley depresses the belt approximately 12,5 mm.

8.21 Rocker arm carrier support basic setting

Each support shall be threaded into the cylinder so that the space between the underside of its fork and the top surface of the cylinder is 31 mm (1 7/32 in).

8.22 Rocker arm carrier basic setting

With the space between the cylinder and the clamping sleeve at approximately 16 mm (5/8 in), the rocker arm carriers shall be horizontal.

8.23 Rocker arm and push rod length basic settings

With the engine crankshaft and flywheel on t.d.c. on the compression stroke, and the rocker arm carriers properly levelled, set the rocker arm adjusting screws at mid-travel and adjust the length of the push rods so the rocker arms are horizontal.

8.24 Basic spark setting

With the engine running and firing, the digital timing indicator or graduated spark quadrant properly calibrated and the ignition timer control mechanism properly set, adjust the cylinder height to a digital counter reading of 264 (uncompensated for barometric pressure) and/or a dial indicator reading of 0,825 in, and then adjust the ignition timer so that the spark timing is 26° b.t.d.c.

NOTE It is inappropriate to convert the dial indicator reading into SI units; see Introduction, paragraph 4.

8.25 Basic ignition timer transducer to rotor vane gap setting

The basic ignition timer transducer to rotor vane gap setting shall be 0,08 mm to 0,13 mm (0,003 in to 0,005 in).

8.26 Basic ignition timer control arm setting

Adjust the length of the ignition control rod so that at the specified cylinder height for the basic spark setting, the centreline of the ignition control arm is horizontal. Tighten the knurled screw that clamps the ignition control arm to the ignition timer and loosen the knurled screw that clamps the ignition timer to the ignition timer bracket. These settings cause spark timing to automatically change as engine cylinder height changes in accordance with either Equation (1) or (2):

$$S = 29,582 - (0,0136 \times C) \quad (1)$$

$$S = 10,163 + (19,19 \times I) \quad (2)$$

where

S is the spark timing, expressed in degrees;

C is the digital counter reading;

I is the dial indicator reading.

8.27 Spark-plug gap

The spark-plug gap shall be 0,51 mm ± 0,13 mm (0,020 in ± 0,005 in).

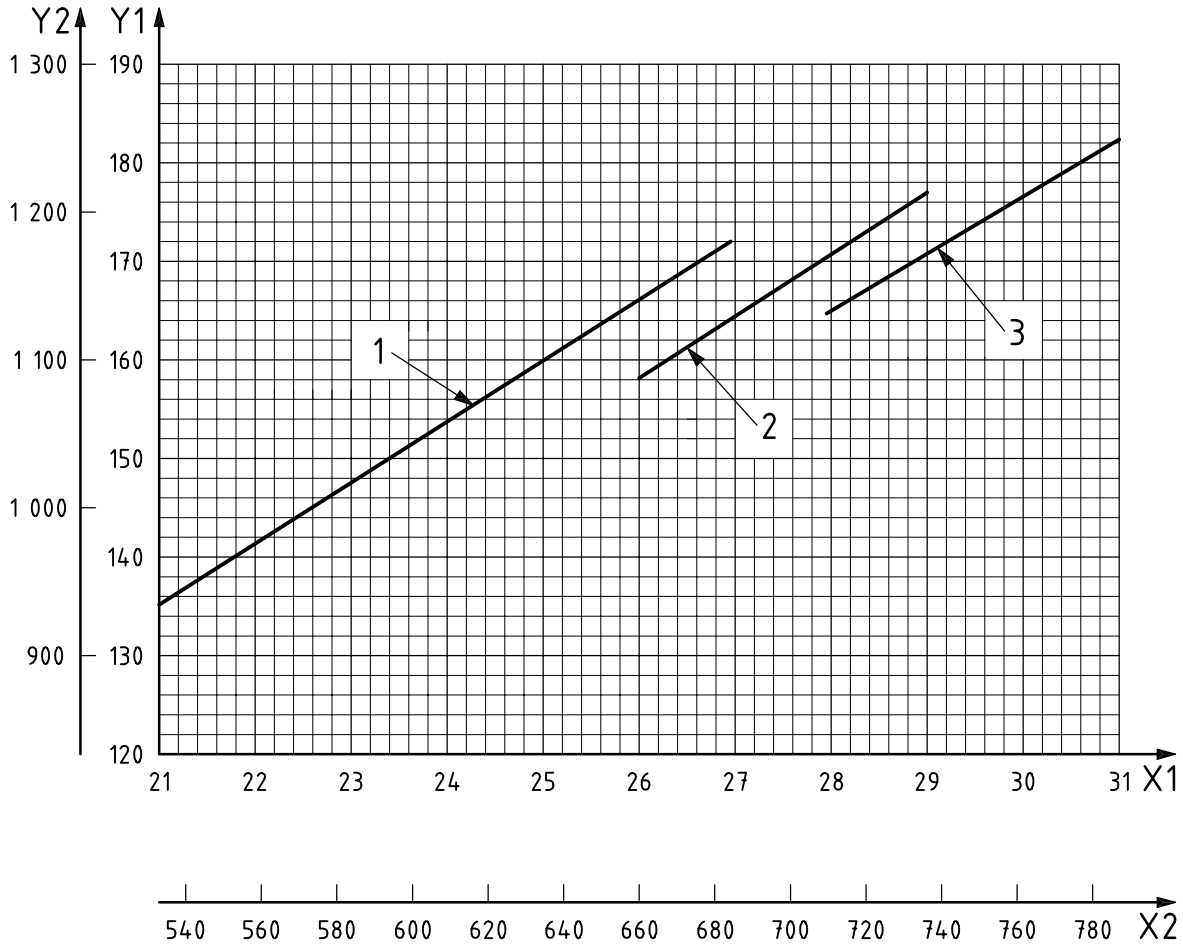
8.28 Basic cylinder height setting

Operate the engine at typical knocking conditions to ensure it is thoroughly warmed up. Shut down the engine. Check that the ignition is off and that fuel cannot enter the combustion chamber. Install a calibrated compression-pressure gauge in the detonation pickup hole of the cylinder. Start and operate the engine under motoring conditions. Adjust the cylinder height to produce the basic compression pressure for the prevailing barometric pressure and selected venturi, in accordance with the information shown in Figure 1. Set the cylinder height indicating devices as follows:

- digital counter reading (uncompensated for barometric pressure) to 930;
- dial indicator reading to 0,352 in.

NOTE It is inappropriate to convert the dial indicator reading into SI units; see Introduction, paragraph 4.

See ASTM D 2700-01a, Annex A4 (Apparatus Assembly and Setting Instructions), for the detailed procedure for indexing the cylinder height that shall apply for this International Standard.



Key

- X1 Barometric pressure, in Hg
- X2 Barometric pressure, mm Hg
- Y1 Compression pressure, psig
- Y2 Compression pressure, kPa
- 1 1,90 cm (3/4 in) venturi; 66,04 cm (26,00 in) Hg base
- 2 1,51 cm (19/32 in) venturi; 71,12 cm (28,00 in) Hg base
- 3 1,43 cm (9/16 in) venturi; 76,00 cm (29,92 in) Hg base

NOTE Basic cylinder height setting:
 digital counter: 930
 dial indicator: 0,352

Figure 1 — Actual compression pressure for setting cylinder height³⁾

3) Extracted, with permission, from ASTM D 2700-01a.

8.29 Fuel-air ratio

For all sample fuels and primary reference fuels, the fuel-air ratio shall be adjusted to maximize knock intensity. When the carburettor sight glasses are used as the indication of mixture strength, the maximum knock condition shall occur when the fuel level in the sight glass is between 17,8 mm (0,7 in) and 45,2 mm (1,7 in), a condition that is dependent on selecting the proper carburettor horizontal jet.

8.30 Carburettor cooling

Circulate coolant (5.2) through the coolant exchangers of the carburettor assembly if there is premature vapourization or bubbling in the sight glasses or transparent fuel lines.

8.31 Knockmeter reading limits

The permissible knockmeter range shall be 20 divisions to 80 divisions to prevent potential nonlinear characteristics that may affect octane ratings.

8.32 Detonation meter spread and time constant settings

Optimize spread and time constant settings of the detonation meter commensurate with reasonable knockmeter reading stability.

Use the procedure given in ASTM D 2700-01a, Annex A4 (Apparatus Assembly and Setting Instructions), to set the detonation meter.

9 Engine calibration and qualification

9.1 General

The engine shall be commissioned in a manner such that all settings and operating conditions are at equilibrium and in compliance with basic engine and instrument specifications.

NOTE Engine warm-up typically requires 1 h to ensure all critical variables are stable.

9.2 Engine fit-for-use qualification

9.2.1 The engine shall be qualified as fit-for-use by rating a toluene standardization fuel (TSF) blend for every MON range in which sample fuels are to be rated in accordance with the following:

- a) at least once during a 12 h operating period;
- b) after an engine has been shut down for more than 2 h;
- c) after an engine has been allowed to operate at non-knocking conditions for more than 2 h;
- d) after a change in barometric pressure of more than 0,68 kPa (0,2 in Hg) from that which prevailed at the time of the previous TSF blend rating for a MON range to be used for rating sample fuels.

9.2.2 The bracketing procedure for rating TSF blends shall be carried out using the cylinder height (compensated for barometric pressure) in accordance with the guide table for standard knock intensity for the MON accepted reference value of the TSF blend.

9.2.3 Standard knock intensity shall be determined using the PRF blend whose whole MON is closest to the MON accepted reference value of the TSF blend.

9.2.4 Carburettor cooling shall not be used.

9.3 Fit-for-use procedure in the 79,8 MON to 94,5 MON range

9.3.1 Select the TSF blend(s) listed in Table 2 for the MON range(s) in which sample fuel ratings are to be made during the operating period.

Table 2 — TSF blend MON, untuned rating tolerances and sample fuel MON range of use

MON of calibrated TSF blend	Untuned rating tolerance	TSF blend composition % (V/V)			Use for sample fuel MON range
		Toluene	Isooctane	Heptane	
81,5 ^a	± 0,3	74	0	26	79,6 to 83,5
85,2 ^a	± 0,3	74	5	21	83,2 to 87,1
88,7 ^a	± 0,3	74	10	16	86,8 to 90,8
92,6 ^b	± 0,4	74	15	11	90,5 to 94,7

^a Blends calibrated by the TCD93 worldwide programme. For further information, refer to the websites listed below:
http://www.astm.org/cgi-bin/SoftCart.exe/SNEWS/MARCH_2004/bradley_mar04.html?L+mystore+dhon6370
<http://www.energyinst.org.uk/index.cfm?PageID=628>

^b Blend calibrated by the ASTM National Exchange Group in 1986. For further information, refer to the websites listed below:
http://www.astm.org/cgi-bin/SoftCart.exe/SNEWS/MARCH_2004/bradley_mar04.html?L+mystore+dhon6370
<http://www.energyinst.org.uk/index.cfm?PageID=628>

9.3.2 Using the standard intake mixture temperature of 149 °C, determine the MON of an untuned TSF blend. The engine shall be qualified as fit-for-use if this TSF blend rating is within the untuned rating tolerance specified in Table 2 and intake mixture temperature tuning is not required, although it is permissible if the rating is more than 0,1 MON from the MON accepted reference value of the TSF blend.

It is permissible to start fit-for-use testing for a new operating period using approximately the same intake mixture temperature tuning adjustment applied for the previous operating period, if both the following conditions are met.

- a) The engine standardization during the last operating period required intake mixture temperature tuning for the last fit-for-use test.
- b) Maintenance has not taken place in the period between fit-for-use tests.

9.3.3 An untuned engine that rates a TSF blend outside the untuned MON rating tolerance specified in Table 2 may be temperature-tuned using an intake mixture temperature neither lower than 141 °C, nor higher than 163 °C. The engine shall be qualified as fit-for-use if the TSF blend rating is within ± 0,1 MON of the MON accepted reference value of the TSF blend. It shall not be used to rate sample fuels, in the applicable MON range for that TSF blend, if it cannot be so qualified. The cause of the inability to rate the TSF blend shall be determined and corrected.

9.4 Fit-for-use procedure below 79,8 MON and above 94,5 MON

9.4.1 Select the TSF blend(s) listed in Table 3 for the MON range(s) in which sample fuel ratings are to be made during the operating period.

9.4.2 Using the standard intake mixture temperature of 149 °C, determine the MON of the TSF blend. The engine shall only be qualified as fit-for-use if the TSF blend rating is within the rating tolerance specified in Table 3 for that TSF blend. Intake mixture temperature tuning is not permitted for these MON rating ranges. If the TSF blend MON rating is outside the rating tolerance specified in Table 3, conduct a thorough investigation to determine and correct the cause. Some engines can be expected to rate outside the rating tolerance for some TSF blend MON levels, and the maintenance of control records can be helpful to demonstrate the typical performance characteristic of that engine.

Table 3 — TSF blend MON, rating tolerance and sample fuel MON range of use

MON of calibrated TSF blend	Rating tolerance	TSF blend composition % (V/V)			Use for sample fuel MON range
		Toluene	Isooctane	Heptane	
58,0	± 1,1	50	0	50	below 62,3
66,9	± 1,1	58	0	42	62,2 to 71,0
74,8	± 1,0	66	0	34	70,7 to 76,7
78,2	± 1,0	70	0	30	76,4 to 79,9
96,6	± 1,2	74	20	6	94,4 to 98,4
99,8 ^a	± 0,9	74	24	2	98,1 to 100,0
100,8	± 1,3	74	26	0	above 100,0

^a Blend calibrated by the ASTM National Exchange Group in 1986. All other calibrated blends by the National Exchange Group and Institute of Petroleum in 1988/89. For further information, refer to the websites listed below:
http://www.astm.org/cgi-bin/SoftCart.exe/SNEWS/MARCH_2004/bradley_mar04.html?L+mystore+dhon6370
<http://www.energyinst.org.uk/index.cfm?PageID=628>

9.5 Checking performance on check fuels

Although engine qualification is dependent solely on the MON ratings of the TSF blend, the use of typical fuels, collected and calibrated as check fuels (5.10), regularly rated and documented using control records and charts, can be useful to demonstrate the on-going performance and credibility of the engine and operating personnel.

10 Procedure

10.1 General

ASTM D 2700-01a incorporates three specific procedural variations for the determination of MON:

- a) procedure A: Bracketing-equilibrium fuel level;
- b) procedure B: Bracketing-dynamic fuel level;
- c) procedure C: Compression ratio.

Only the original procedure, now identified in the ASTM standard as the bracketing-equilibrium fuel level procedure, is included in this International Standard. However, all three procedures have equivalent precision in the MON range of typical commercial motor fuel and can be used for ratings in specific MON ranges.

Check that all engine operating conditions are in compliance and equilibrated with the engine running on a typical fuel.

10.2 Start-up

Determine that the engine is fit-for-use. If tuning of the intake mixture temperature is utilized to qualify the engine, the selected intake mixture temperature for the MON of the appropriate TSF blend shall be used, during the operating period, to rate every sample fuel in the applicable MON range of use for that TSF blend.

10.3 Calibration

10.3.1 Calibrate the engine and instrumentation to establish standard knock intensity using a PRF blend whose MON is close to that of the sample fuels to be tested.

10.3.2 Set the cylinder height (compensated for barometric pressure) in accordance with the guide table value (given in Annex A6 of ASTM D 2700-01a) for the MON of the PRF selected.

10.3.3 Operate the engine utilizing the PRF and vary the fuel-air ratio to establish the setting that maximizes the knockmeter reading.

10.3.4 Adjust the detonation meter controls to produce a knockmeter reading of 50 divisions \pm 2 divisions with an optimized spread commensurate with knockmeter stability.

NOTE Guide tables for standard knock intensity at standard barometric pressure listing the cylinder heights for each MON (in tenths) over the range from 40 MON to 120 MON are given in ASTM D 2700-01a, Annex A6 (Guide Tables of Constant Knock Intensity), for each carburettor venturi size. To complement these tables, Annex A6 also includes a table for compensation of guide table cylinder heights when the barometric pressure is either below or above standard barometric pressure.

10.3.5 If the MON of a sample fuel is indicated to be higher than 100, the standard knock intensity shall be established using one of the isooctane and TEL PRF blends that will bracket the sample fuel. Several trials may be required in order to select the appropriate PRF. In addition, use the PRF blends specific to the MON rating range as specified in Table 4. Adjust the detonation meter settings such that the detonation meter spread is maintained as large as possible, despite knockmeter reading instability.

10.4 Sample fuel

10.4.1 Operate the engine on the sample fuel and check that the fuel system is free of vapour bubbles.

10.4.2 Adjust the cylinder height to result in a mid-scale knockmeter reading.

10.4.3 Adjust the fuel-air ratio and determine the maximum knockmeter reading attainable. If necessary, readjust the cylinder height such that the maximum knockmeter reading occurs at 50 divisions \pm 2 divisions.

10.4.4 Record the sample fuel knockmeter reading.

10.5 Primary reference fuel No. 1

10.5.1 Based on the cylinder height used for the sample fuel, refer to the appropriate guide table given in ASTM D 2700 and select a PRF that can be expected to have a MON close to that of the sample fuel.

10.5.2 Prepare a fresh batch of the PRF. Operate the engine using this PRF and check that the fuel system is free of vapour bubbles.

10.5.3 Without changing the cylinder height from that used for the sample fuel, adjust the fuel-air ratio and determine the maximum knockmeter reading for the PRF.

10.5.4 Record the PRF knockmeter reading.

10.6 Primary reference fuel No. 2

10.6.1 Select a second PRF that will meet the maximum permissible bracketing difference requirements specified in Table 4, and that can be expected to cause the knockmeter readings for the two PRF blends to bracket that of the sample fuel.

10.6.2 Prepare a fresh batch of the second PRF. Operate the engine using this PRF and check that the fuel system is free of vapour bubbles.

10.6.3 Without changing the cylinder height from that used for the sample fuel, adjust the fuel-air ratio and determine the maximum knockmeter reading for the PRF.

10.6.4 Record the equilibrium knockmeter reading.

10.6.5 If the knockmeter reading for the sample fuel is bracketed by those of the PRF blends, continue the test. Otherwise, try additional PRF blends until this requirement is satisfied.

Table 4 — Maximum permissible bracketing PRF MON differences

MON range of sample fuel	Maximum permissible MON difference of PRF blends
40 to 72	4,0
72 to 80	2,4
80 to 100	2,0
100,0 to 100,7	Use only 100,0 and 100,7 MON PRF blends.
100,7 to 101,3	Use only 100,7 and 101,3 MON PRF blends.
101,3 to 102,5	Use only 101,3 and 102,5 MON PRF blends.
102,5 to 103,5	Use only 102,5 and 103,5 MON PRF blends.
103,5 to 108,6	Use PRF blends with TEL contents 0,053 ml/l (0,2 ml/U.S. gal) apart.
108,6 to 115,5	Use PRF blends with TEL contents 0,132 ml/l (0,5 ml/U.S. gal) apart.
115,5 to 120,3	Use PRF blends with TEL contents 0,264 ml/l (1,0 ml/U.S. gal) apart.

10.7 Additional measurement readings

10.7.1 Without changing the cylinder height, operate the engine on the sample fuel followed by PRF No. 2, and then PRF No. 1, to obtain a second series of knockmeter readings. For each fuel, ensure that the fuel-air ratio for maximum knockmeter reading is used and allow operation to reach equilibrium before recording the knockmeter readings.

10.7.2 If in the process of calculating the MON of the sample fuel the first two series of knockmeter readings do not meet the criteria specified in 11.3, obtain a third series of readings on the three fuels.

11 Calculation

11.1 Calculate the MON of the first series of knockmeter readings by interpolation of their values proportioned to the octane numbers of the bracketing reference fuels in accordance with Equation (3):

$$Y_{\text{MON,S}} = Y_{\text{MON,LRF}} + \left(\frac{X_{\text{KI,LRF}} - X_{\text{KI,S}}}{X_{\text{KI,LRF}} - X_{\text{KI,HRF}}} \right) (Y_{\text{MON,HRF}} - Y_{\text{MON,LRF}}) \quad (3)$$

where

$Y_{\text{MON,S}}$ is the MON of the sample;

$Y_{\text{MON,LRF}}$ is the MON of the low reference fuel;

$Y_{\text{MON,HRF}}$ is the MON of the high reference fuel;

$X_{\text{KI,S}}$ is the knockmeter reading of the sample fuel;

$X_{\text{KI,LRF}}$ is the knockmeter reading of the low reference fuel;

$X_{\text{KI,HRF}}$ is the knockmeter reading of the high reference fuel.

11.2 Calculate the MON of the second series of knockmeter readings.

11.3 The average MON based on two series of knockmeter readings constitutes a rating if the difference in the calculated MON values for each of the individual series of knockmeter readings is no greater than 0,3 MON, the average of the first and the second sample fuel knockmeter reading is between 45 and 55, and the cylinder height (compensated for barometric pressure) used for the rating is within the specified guide table limits (digital counter reading = ± 20, or dial indicator reading = ± 0,014 in).

NOTE It is inappropriate to convert the dial indicator reading into SI units; see Introduction, paragraph 4.

11.4 If either the calculated MON difference or the average knockmeter reading criteria is not met, a third series of knockmeter readings on the sample fuel and reference fuels No. 1, and No. 2 shall be obtained. The second and third series of readings can then constitute a rating if they meet the criteria specified in 11.3.

11.5 If the cylinder height used for the rating is outside the guide table limit, conduct a new rating after readjusting the detonation meter settings to establish the appropriate standard knock intensity.

12 Expression of results

Report the calculated motor octane number in accordance with the requirements of Table 5. When the calculated MON value ends in exactly 5 in the place just beyond that to which it is to be reported, round to the nearest even digit.

Table 5 — Significant digits for reporting motor octane number

Motor octane number range	Report to
Below 72,0	nearest integer
72,0 to 103,5	nearest tenth
Above 103,5	nearest integer

EXAMPLE 67,5 and 68,5 would be rounded to 68 as the nearest integer; 89,55 and 89,65 would be rounded to 89,6 as the nearest tenth.

13 Precision

13.1 General

ASTM D 2700 incorporates three specific procedural variations for the determination of MON. Both the bracketing-equilibrium fuel level and compression ratio procedures have been widely used for a number of years and the precision data reflect their equivalent performance. The compression ratio procedure is allowed for ratings between 80 MON and 100 MON for the purposes of this International Standard. The bracketing-dynamic fuel level procedure was examined for equivalency between 80 MON and 90 MON using four commercial fuels, three TSF blends and eight oxygenate-containing fuels, as detailed in ASTM Research Report RR:D02-1343^[4].

13.2 Repeatability (*r*) for ratings at barometric pressures of 94,6 kPa (28,0 in of Hg) and higher

The difference between two test results, obtained by the same operator with the same apparatus under constant operating conditions on identical test material would in the long run, in the normal and correct operation of the test method, exceed the values given in Table 6 in only one case in 20.

13.3 Reproducibility (*R*) for ratings at barometric pressures of 94,6 kPa (28,0 in of Hg) and higher

The difference between two single and independent test results, obtained by different operators working in different laboratories on identical test material would in the long run, in the normal and correct operation of the test method, exceed the values given in Table 6 in only one case in 20.

Table 6 — Motor octane number repeatability and reproducibility limits

Average motor octane number level	Repeatability, <i>r</i>	Reproducibility, <i>R</i>
Below 80,0	no current data	no current data
80,0 to 90,0	0,2	0,9
90,0 to 102,0	no current data	no current data
102 to 103	0,6	2,0
Above 103,0	no current data	no current data

13.4 Precision at lower barometric pressure

The precision of this test method when performed at barometric pressures of less than 94,6 kPa (28,0 in of Hg) has not been adequately determined. However, reproducibility for the 80,0 MON to 90,0 MON range at altitude locations, based on the ASTM Rocky Mountain Regional Group interlaboratory results⁴⁾, would, in the long run, in the normal operation of the test method, exceed approximately 1,4 MON in only one case in 20.

NOTE Repeatability precision limits for the 80 MON to 90 MON range are based on the ASTM Motor National Exchange Group (NEG) program data from 1983 through 1987 and 1994⁴⁾, during which periods, the monthly samples were rated twice on the same day by the same operator on one engine in each of the member laboratories⁵⁾.

Reproducibility precision limits for the 80 MON to 90 MON range are based on the data from the NEG⁴⁾ and the Institute of Petroleum monthly exchange programs from 1988 through 1994⁴⁾, as well as those of the Institut Français du Pétrole monthly exchange program from 1991 through 1994⁴⁾. Sample fuels containing oxygenates (alcohols or ethers), in concentrations typical of commercial fuel, were included in these data.

Repeatability and reproducibility precision limit values above 100 MON are based on ASTM Aviation NEG quarterly sample data from 1988 through 1994⁴⁾.

14 Test report

14.1 Motor spark-ignition engine fuels

The test report for motor spark-ignition engine fuels shall contain at least the following information:

- a) a reference to this International Standard;
- b) the type and complete identification of the product tested;
- c) the results of the test (see Clause 12);
- d) any deviation, by agreement or otherwise, from the procedures specified;
- e) the date of the test.

4) For further information, refer to the websites listed below:

http://www.astm.org/cgi-bin/SoftCart.exe/SNEWS/MARCH_2004/bradley_mar04.html?L+mystore+dhon6370
<http://www.energyinst.org.uk/index.cfm?PageID=628>

5) See ASTM Research Report RR:D02-1383⁵⁾ for a listing of the data and the analyses used to establish precision.

14.2 Aviation piston-engine fuel

The test report for an aviation piston-engine fuel shall contain at least the following information:

- a) a reference to this International Standard;
- b) the type and complete identification of the product tested;
- c) MON results of the test (see Clause 12);
- d) the aviation method rating determined by conversion of the MON result using Table 7. Aviation method ratings that are 100 or less are reported as octane number. Aviation method ratings that are higher than 100 are reported as performance number.
- e) any deviation, by agreement or otherwise, from the procedures specified;
- f) the date of the test.

Table 7 — Conversion of MON to aviation method rating

MON	Aviation method rating				
	0,0	0,2	0,4	0,6	0,8
90	90,15	90,37	90,58	90,79	91,01
91	91,22	91,43	91,65	91,86	92,07
92	92,29	92,50	92,71	92,92	93,13
93	93,35	93,56	93,77	93,98	94,19
94	94,40	94,61	94,82	95,04	95,25
95	95,46	95,67	95,88	96,09	96,29
96	96,50	96,71	96,92	97,13	97,34
97	97,55	97,76	97,96	98,17	98,38
98	98,57	98,74	98,91	99,08	99,25
99	99,43	99,60	99,77	99,25	100,54
100	101,07	101,60	102,14	102,67	103,21
101	103,74	104,27	104,81	105,34	105,88
102	106,41	106,94	107,48	108,01	108,55
103	109,08	109,61	110,15	110,68	111,22
104	111,75	112,28	112,82	113,35	113,89
105	114,42	114,95	115,49	116,02	116,56
106	117,09	117,62	118,16	118,69	119,23
107	119,76	120,29	120,83	121,36	121,90
108	122,43	122,96	123,50	124,03	124,57
109	125,10	125,63	126,17	126,70	127,24
110	127,77	128,30	128,84	129,37	129,91

NOTE This table converts motor octane numbers to aviation method ratings equivalent to those of now-discontinued ASTM D 614^[2], *Test for Knock Characteristics of Aviation Fuels by the Aviation Method*.

NOTE See ASTM Research Report RR:D02-69^[3] for information relative to the correlation of ASTM D 357^[1] (now D 2700) MON data to ASTM D 614^[2] ratings.

NOTE Aviation ratings above the heavy line in the table are in terms of octane number and ratings below the line are in terms of performance number.

Bibliography

- [1] ASTM D 357-69, *Method of Test for Knock Characteristics of Motor Fuels Below 100 Octane Number by the Motor Method*
- [2] ASTM D 614-67, *Method of Test for Knock Characteristics of Aviation Fuels by the Aviation Method*
- [3] RR:D02-69, *Aviation Gasoline Antiknock Quality by ASTM Methods D 614 and D357*
- [4] RR:D02-1343, *Validation Study of the Falling Level Technique for Research and Motor Octane Determination*
- [5] RR:D02-1383, *Research Report for ASTM D2699, Test for Knock Characteristics of Motor Fuels by the Research Method*

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