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Standard Test Method for Research Octane Number of Spark-Ignition Engine Fuel[1]

This standard is issued under the fixed designation D 2699; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This laboratory test method covers the quantitative determination of the knock rating of liquid spark-ignition engine fuel in terms of Research O.N., except that this test method may not be applicable to fuel and fuel components that are primarily oxygenates.[2] The sample fuel is tested using a standardized single cylinder, four-stroke cycle, variable compression ratio, carbureted, CFR engine run in accordance with a defined set of operating conditions. The O.N. scale is defined by the volumetric composition of PRF blends. The sample fuel knock intensity is compared to that of one or more PRF blends. The O.N. of the PRF blend that matches the K.I. of the sample fuel establishes the Research O.N.

1.2 The O.N. scale covers the range from 0 to 120 octane number but this test method has a working range from 40 to 120 Research O.N. Typical commercial fuels produced for spark-ignition engines rate in the 88 to 101 Research O.N. range. Testing of gasoline blend stocks or other process stream materials can produce ratings at various levels throughout the Research O.N. range.

1.3 The values of operating conditions are stated in SI units and are considered standard. The values in parentheses are the historical inch-pound units. The standardized CFR engine measurements continue to be in inch-pound units only because of the extensive and expensive tooling that has been created for this equipment.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.* For specific hazard statements, see Section 8, 13.4.1, 14.5.1, 15.6.1, Annex A1, A2.3.9, A2.4.8, A3.2.7.2(*7*), A4.2.3.1, A4.2.3.3(*6*) and (*9*), A4.3.5, X2.3.7, X3.2.3.1, X3.3.4.1, X3.3.9.3, X3.3.11.4, and X3.5.1.8.

2. Referenced Documents

2.1 *ASTM Standards:*

D 1193 Specification for Reagent Water[3]

D 1744 Test Method for Water in Liquid Petroleum Products by Karl Fischer Reagent[4]

D 2268 Test Method for Analysis of High-Purity *n*-Heptane and *Iso*octane by Capillary Gas Chromatography[4]

D 2360 Test Method for Trace Impurities in Monocyclic Aromatic Hydrocarbons by Gas Chromatography[5]

D 2700 Test Method for Motor Octane Number of Spark-Ignition Engine Fuel[6]

D 2885 Test Method for Research and Motor Method Octane Ratings Using On-Line Analyzers[6]

D 3116 Test Method for Trace Amounts of Lead in Gasoline[7]

D 3237 Test Method for Lead in Gasoline by Atomic Absorption Spectrometry[8]

D 3703 Test Method for Peroxide Number of Aviation Turbine Fuels[8]

D 4057 Practice for Manual Sampling of Petroleum and Petroleum Products[8]

D 4175 Terminology Relating to Petroleum, Petroleum Products, and Lubricants[8]

D 4177 Practice for Automatic Sampling of Petroleum and Petroleum Products[8]

D 4814 Specification for Automotive Spark-Ignition Engine Fuel[8]

E 1 Specification for ASTM Thermometers[9]

E 456 Terminology Relating to Quality and Statistics[10]

[1] This test method is under the jurisdiction of ASTM Committee D02 on Petroleum Products and Lubricants and is the direct responsibility of Subcommittee D02.01 on Combustion Characteristics.

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[2] Motor O.N., determined using Test Method D 2700, is a companion method to provide a similar but typically lower octane rating under more severe operating conditions.

[3] *Annual Book of ASTM Standards*, Vol 11.01.

[4] *Annual Book of ASTM Standards*, Vol 05.01.

[5] *Annual Book of ASTM Standards*, Vol 06.04.

[6] *Annual Book of ASTM Standards*, Vol 05.05.

[7] Discontinued; see *1994 Annual Book of ASTM Standards*, Vol 05.02.

[8] *Annual Book of ASTM Standards*, Vol 05.02.

[9] *Annual Book of ASTM Standards*, Vol 14.03.

[10] *Annual Book of ASTM Standards*, Vol 14.02.

E 542 Practice for Calibration of Laboratory Volumetric Apparatus[11]

2.2 *ANSI Standard:*[12]

C-39.1 Requirements for Electrical Analog Indicating Instruments

3. Terminology

3.1 *Definitions:*

3.1.1 *accepted reference value, n*—a value that serves as an agreed-upon reference for comparison, and which is derived as: (*1*) a theoretical or established value, based on scientific principles, or (*2*) an assigned or certified value, based on experimental work of some national or international organization, or (*3*) a consensus or certified value, based on collaborative experimental work under the auspices of a scientific or engineering group. **(E 456)**

3.1.1.1 *Discussion*—In the context of this test method accepted reference value is understood to apply to the Research octane number of specific reference materials determined empirically under reproducibility conditions by the National Exchange Group or another recognized exchange testing organization.

3.1.2 *Check Fuel, n—for quality control testing,* a spark-ignition engine fuels of selected characteristics having an octane number accepted reference value ($O.N._{ARV}$) determined by round-robin testing under reproducibility conditions.

3.1.3 *cylinder height, n—for the CFR engine,* the relative vertical position of the engine cylinder with respect to the piston at top dead center (tdc) or the top machined surface of the crankcase.

3.1.3.1 *dial indicator reading, n—for the CFR engine,* a numerical indication of cylinder height, in thousandths of an inch, indexed to a basic setting at a prescribed compression pressure when the engine is motored.

3.1.3.2 *digital counter reading, n—for the CFR engine,* a numerical indication of cylinder height, indexed to a basic setting at a prescribed compression pressure when the engine is motored.

3.1.4 *detonation meter, n—for knock testing,* the signal conditioning instrumentation that accepts the electrical signal from the detonation pickup and provides an output signal for display.

3.1.5 *detonation pickup, n—for knock testing,* a magnetostrictive-type transducer that threads into the engine cylinder and is exposed to combustion chamber pressure to provide an electrical signal that is proportional to the rate-of-change of cylinder pressure.

3.1.6 *dynamic fuel level, n—for knock testing,* test procedure in which the fuel-air ratio for maximum knock intensity for sample and reference fuels is determined using the falling level technique that changes carburetor fuel level from a high or rich mixture condition to a low or lean mixture condition, at a constant rate, causing knock intensity to rise to a maximum and then decrease, thus permitting observation of the maximum knockmeter reading.

3.1.7 *equilibrium fuel level, n—for knock testing,* test procedure in which the fuel-air ratio for maximum knock intensity for sample and reference fuels is determined by making incremental step changes in carburetor fuel level, observing the equilibrium knock intensity for each step and selecting the level that produces the highest knock intensity reading.

3.1.8 *firing, n—for the CFR engine,* operation of the CFR engine with fuel and ignition.

3.1.9 *fuel-air ratio for maximum knock intensity, n—for knock testing,* that proportion of fuel to air that produces the highest knock intensity for each fuel in the knock testing unit, provided this occurs within specified carburetor fuel level limits.

3.1.10 *guide tables, n—for knock testing,* the specific relationship between cylinder height (compression ratio) and octane number at standard knock intensity for specific primary reference fuel blends tested at standard or other specified barometric pressure.

3.1.11 *knock, n—in a spark-ignition engine,* abnormal combustion, often producing audible sound, caused by autoignition of the air/fuel mixture. **(D 4175)**

3.1.12 *knockmeter, n—for knock testing,* the 0 to 100 division indicating meter that displays the knock intensity signal from the detonation meter.

3.1.13 *knock intensity, n—for knock testing,* a measure of the level of knock.

3.1.14 *motoring, n—for the CFR engine,* operation of the CFR engine without fuel and with the ignition shut off.

3.1.15 *octane number, n—for spark-ignition engine fuel,* any one of several numerical indicators of resistance to knock obtained by comparison with reference fuels in standardized engine or vehicle tests. **(D 4175)**

3.1.15.1 *Research octane number, n—for spark-ignition engine fuel,* the numerical rating of knock resistance obtained by comparison of its knock intensity with that of primary reference fuel blends when both are tested in a standardized CFR engine operating under the conditions specified in this test method.

3.1.16 *oxygenate, n*—an oxygen-containing organic compound, which may be used as a fuel or fuel supplement, for example, various alcohols and ethers. **(D 4175)**

3.1.17 *primary reference fuels, n—for knock testing, iso*octane, *n*-heptane, volumetrically proportioned mixtures of *iso*octane with *n*-heptane, or blends of tetraethyllead in *iso*octane that define the octane number scale.

3.1.17.1 *primary reference fuel blends below 100 octane, n*—the volume % of *iso*octane in a blend with *n*-heptane that defines the octane number of the blend, *iso*octane being assigned as 100 and *n*-heptane as 0 octane number.

3.1.17.2 *primary reference fuel blends above 100 octane, n*—the millilitres per U.S. gallon of tetraethyllead in *iso*octane that define octane numbers above 100 in accordance with an empirically determined relationship.

3.1.18 *repeatability conditions, n*—conditions where independent test results are obtained with the same method on identical test items in the same laboratory by the same operator using the same equipment within short intervals of time. **(E 456)**

[11] *Annual Book of ASTM Standards*, Vol 14.04.

[12] Available from American National Standards Institute, 11 W. 42nd St., 13th Floor, New York, NY 10036.

3.1.18.1 *Discussion*—In the context of this test method, a short time interval between two ratings on a sample fuel is understood to be not less than the time to obtain at least one rating on another sample fuel between them but not so long as to permit any significant change in the sample fuel, test equipment, or environment.

3.1.19 *reproducibility conditions*, *n*—conditions where test results are obtained with the same method on identical test items in different laboratories with different operators using different equipment. **(E 456)**

3.1.20 *spread*, *n—in knock measurement*, the sensitivity of the detonation meter expressed in knockmeter divisions per octane number.

3.1.21 *standard knock intensity*, *n—for knock testing*, that level of knock established when a primary reference fuel blend of specific octane number is used in the knock testing unit at maximum knock intensity fuel-air ratio, with the cylinder height (dial indicator or digital counter reading) set to the prescribed guide table value. The detonation meter is adjusted to produce a knockmeter reading of 50 for these conditions.

3.1.22 *toluene standardization fuels, n—for knock testing*, those volumetrically proportioned blends of two or more of the following: reference fuel grade toluene, *n*-heptane, and *iso*octane that have prescribed rating tolerances for O.N.$_{ARV}$ determined by round-robin testing under reproducibility conditions.

3.2 *Abbreviations:*

3.2.1 *ARV* = accepted reference value

3.2.2 *C.R.* = compression ratio

3.2.3 *IAT* = intake air temperature

3.2.4 *K.I.* = knock intensity

3.2.5 *O.N.* = octane number

3.2.6 *PRF* = primary reference fuel

3.2.7 *TSF* = toluene standardization fuel

4. Summary of Test Method

4.1 The Research O.N. of a spark-ignition engine fuel is determined using a standard test engine and operating conditions to compare its knock characteristic with those of PRF blends of known O.N. Compression ratio and fuel-air ratio are adjusted to produce standard K.I. for the sample fuel, as measured by a specific electronic detonation meter instrument system. A standard K.I. guide table relates engine C.R. to O.N. level for this specific method. The fuel-air ratio for the sample fuel and each of the primary reference fuel blends is adjusted to maximize K.I. for each fuel.

4.1.1 The fuel-air ratio for maximum K.I. may be obtained (*1*) by making incremental step changes in mixture strength, observing the equilibrium K.I. value for each step, and then selecting the condition that maximizes the reading or (*2*) by picking the maximum K.I. as the mixture strength is changed from either rich-to-lean or lean-to-rich at a constant rate.

4.2 *Bracketing Procedures*—The engine is calibrated to operate at standard K.I. in accordance with the guide table. The fuel-air ratio of the sample fuel is adjusted to maximize the K.I., and then the cylinder height is adjusted so that standard K.I. is achieved. Without changing cylinder height, two PRF blends are selected such that, at their fuel-air ratio for maximum K.I., one knocks harder (higher K.I.) and the other softer (lower K.I.) than the sample fuel. A second set of K.I. measurements for sample fuel and PRF blends is required, and the sample fuel octane number is calculated by interpolation in proportion to the differences in average K.I. readings. A final condition requires that the cylinder height used shall be within prescribed limits around the guide table value for the calculated O.N. Bracketing procedure ratings may be determined using either the equilibrium fuel level or dynamic fuel level fuel-air ratio approach.

4.3 *C.R. Procedure*—A calibration is performed to establish standard K.I. using the cylinder height specified by the guide table for the O.N. of the selected PRF. The fuel-air ratio of the sample fuel is adjusted to maximize the K.I. under equilibrium conditions; the cylinder height is adjusted so that standard K.I. is achieved. The calibration is reconfirmed and the sample fuel rating is repeated to establish the proper conditions a second time. The average cylinder height reading for the sample fuel, compensated for barometric pressure, is converted directly to O.N., using the guide table. A final condition for the rating requires that the sample fuel O.N. be within prescribed limits around that of the O.N. of the single PRF blend used to calibrate the engine to the guide table standard K.I. condition.

5. Significance and Use

5.1 Research O.N. correlates with commercial automotive spark-ignition engine antiknock performance under mild conditions of operation.

5.2 Research O.N. is used by engine manufacturers, petroleum refiners and marketers, and in commerce as a primary specification measurement related to the matching of fuels and engines.

5.2.1 Empirical correlations that permit calculation of automotive antiknock performance are based on the general equation:

$$\text{Road O.N.} = (k_1 \times \text{Research O.N.}) + (k_2 \times \text{Motor O.N.}) + k_3 \quad (1)$$

Values of k_1, k_2, and k_3 vary with vehicles and vehicle populations and are based on road-O.N. determinations.

5.2.2 Research O.N., in conjunction with Motor O.N., defines the antiknock index of automotive spark-ignition engine fuels, in accordance with Specification D 4814. The antiknock index of a fuel approximates the Road octane ratings for many vehicles, is posted on retail dispensing pumps in the U.S., and is referred to in vehicle manuals.

$$\text{Antiknock index} = 0.5 \text{ Research O.N.} + 0.5 \text{ Motor O.N.} + 0 \quad (2)$$

This is more commonly presented as:

$$\text{Antiknock Index} = \frac{(R + M)}{2} \quad (3)$$

5.2.3 Research O.N. is also used either alone or in conjunction with other factors to define the Road O.N. capabilities of spark-ignition engine fuels for vehicles operating in areas of the world other than the United States.

5.3 Research O.N. is used for measuring the antiknock performance of spark-ignition engine fuels that contain oxygenates.

5.4 Research O.N. is important in relation to the specifications for spark-ignition engine fuels used in stationary and other nonautomotive engine applications.

6. Interferences

6.1 Certain gases and fumes that can be present in the area where the knock testing unit is located may have a measurable effect on the Research O.N. test result.

6.1.1 Halogenated refrigerant used in air conditioning and refrigeration equipment can promote knock. Halogenated solvents can have the same effect. If vapors from these materials enter the combustion chamber of the CFR engine, the Research O.N. obtained for sample fuels can be depreciated.

6.2 Electrical power subject to transient voltage or frequency surges or distortion can alter CFR engine operating conditions or knock measuring instrumentation performance and thus affect the Research O.N. obtained for sample fuels.

7. Apparatus

7.1 *Engine Equipment*[13]—This test method uses a single cylinder, CFR engine that consists of standard components as follows: crankcase, a cylinder/clamping sleeve assembly to provide continuously variable compression ratio adjustable with the engine operating, a thermal syphon recirculating jacket coolant system, a multiple fuel tank system with selector valving to deliver fuel through a single jet passage and carburetor venturi, an intake air system with controlled temperature and humidity equipment, electrical controls, and a suitable exhaust pipe. The engine flywheel is belt connected to a special electric power-absorption motor utilized to both start the engine and as a means to absorb power at constant speed when combustion is occurring (engine firing). See Fig. 1.

7.1.1 See Annex A2 for details and description of all critical, non-critical, and equivalent engine equipment.

7.2 *Instrumentation*[13]—This test method uses electronic detonation metering instrumentation to measure the intensity of combustion knock as well as conventional thermometry, gages, and general purpose meters.

7.2.1 See Annex A3 for details and description of all critical, non-critical, and equivalent instrumentation.

7.3 *Reference and Standardization Fuel Dispensing Equipment*—This test method requires repeated volumetric blending of reference fuels and TSF materials. In addition, volumetric blending of dilute tetraethyllead in *iso*octane may be performed on-site for making rating determinations above 100 O.N. Blending shall be performed accurately because rating error is proportional to blending error. A set of burets, or accurate volumetric apparatus, shall be used and the desired batch quantity shall be collected in a glass, metal, or selected plastic container and thoroughly mixed before being introduced to the engine fuel system.

7.3.1 Calibrated burets or volumetric apparatus having a capacity of 200 to 500 mL and a maximum volumetric tolerance of ±0.2 % shall be used for preparation of reference and standardization fuel blends. Calibration shall be verified in accordance with Practice E 542.

7.3.1.1 Calibrated burets shall be outfitted with a dispensing valve and delivery tip to accurately control dispensed volume. The delivery tip shall be of such design that shut-off tip discharge does not exceed 0.5 mL.

7.3.1.2 The rate of delivery from the dispensing system shall not exceed 400 mL per min.

7.3.1.3 The set of burets for the reference and standardization fuels shall be installed in such a manner and be supplied with fluids such that all components of each batch or blend are dispensed at the same temperature.

7.3.2 A calibrated buret, pipette assembly, or other liquid dispensing apparatus having a capacity of not more than 4.0 mL and a critically controlled volumetric tolerance shall be used for dispensing dilute tetraethyllead into 400-mL batches of *iso*octane. Calibration of the dispensing apparatus shall be verified in accordance with Practice E 542.

7.3.3 See Appendix X1 for dispensing system information.

7.4 *Auxiliary Apparatus*:

7.4.1 *Special Maintenance Tools*—A number of specialty tools and measuring instruments should be utilized for easy, convenient, and effective maintenance of the engine and testing equipment. Lists and descriptions of these tools and instruments are available from the manufacturer of the engine equipment and those organizations offering engineering and service support for this test method.

7.4.2 *Ventilation Hoods*—Handling of reference and standardization fuels, dilute tetraethyllead, and test samples having various hydrocarbon compositions is best conducted in a well ventilated space or in a laboratory hood where air movement across the area is sufficient to prevent operator inhalation of vapors.

7.4.2.1 General purpose laboratory hoods are typically effective for handling hydrocarbon fuel blending.[14]

7.4.2.2 A blending hood meeting the requirements for dispensing toxic material shall be utilized in testing laboratories that choose to prepare leaded *iso*octane PRF blends on-site.

8. Reagents and Reference Materials

8.1 *Cylinder Jacket Coolant*—Water shall be used in the cylinder jacket for laboratory locations where the resultant boiling temperature shall be 100 ± 1.5°C (212 ± 3°F). 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 multifunctional water treatment material should be used in the coolant to minimize corrosion and mineral scale that can alter heat transfer and rating results. (**Warning**—Ethylene glycol based antifreeze is poisonous and may be harmful or fatal if inhaled or swallowed. See Annex A1.)

8.1.1 Water shall be understood to mean reagent water conforming to Type IV, of Specification D 1193.

8.2 *Engine Crankcase Lubricating Oil*—An SAE 30 viscosity grade oil meeting the current API service classification for spark-ignition engines shall be used. It shall contain a detergent additive and have a kinematic viscosity of 9.3 to 12.5 mm^2 per s (cSt) at 100°C (212°F) and a viscosity index of not less than 85. Oils containing viscosity index improvers shall not be used.

[13] Engine equipment and instrumentation are available from the single source manufacturer, Waukesha Engine, Dresser Inc., 1000 West St. Paul Ave., Waukesha, WI 53188. Waukesha Engine also has CFR engine authorized sales and service organizations in selected geographical areas.

[14] Refer to *Industrial Ventilation Manual*, published by the American Conference of Governmental Industrial Hygienists, Cincinnati, OH.