



Designation: **D2885 – 13** **D2885 – 19**

# Standard Test Method for Determination of Octane Number of Spark-Ignition Engine Fuels by On-Line Direct Comparison Technique<sup>1</sup>

This standard is issued under the fixed designation D2885; 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 ( $\epsilon$ ) indicates an editorial change since the last revision or reapproval.

*This standard has been approved for use by agencies of the U.S. Department of Defense.*

## 1. Scope\*

1.1 This test method covers the quantitative online determination by direct comparison of the difference in knock rating or delta octane number of a stream sample of spark-ignition engine fuel from that of a comparison reference fuel.

1.2 This test method covers the methodology for obtaining an octane number using the measured delta octane number and the octane number of the comparison reference fuel.

1.3 The comparison reference fuel is required to be of essentially the same composition as the stream sample to be analyzed and can be a secondary fuel termed standard fuel or a tertiary fuel termed prototype fuel.

1.4 The test method utilizes a knock testing unit/automated analyzer system that incorporates computer control of a standardized single-cylinder, four-stroke cycle, variable compression ratio, carbureted, CFR engine with appropriate auxiliary equipment using either Test Method **D2699** Research method or Test Method **D2700** Motor method operating conditions.

1.4.1 Knock measurements are based on operation of both fuels at the specific fuel-air ratio that produces maximum knock intensity for that fuel.

1.4.2 Measured differences in knock intensity are scaled to provide a positive or negative delta octane number of the stream sample from the comparison reference fuel when the fuels are compared at the same compression ratio.

1.4.3 Measured differences in compression ratio are scaled to provide a positive or negative delta octane number of the stream sample from the comparison reference fuel when the fuels are compared at the same knock intensity.

1.5 This test method is limited to testing 78 to 102 octane number spark-ignition engine fuels using either research or motor method conditions.

1.6 The octane number difference between the stream sample and the applicable comparison reference fuel is self-limiting by specifications imposed upon the standard and prototype fuels.

1.7 Specifications for selection, preparation, storage, and dispensing of standard and prototype fuels are provided. Detailed procedures for determination of an appropriate assigned octane number for both standard and prototype fuels are also incorporated.

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

1.9 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* For more specific warning statements, see Section 8 and **Annex A1**.

1.10 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

<sup>1</sup> This test method is under the jurisdiction of ASTM Committee **D02** on Petroleum Products—Products, Liquid Fuels, and Lubricants and is the direct responsibility of Subcommittee **D02.01** on Combustion Characteristics.

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\*A Summary of Changes section appears at the end of this standard

## 2. Referenced Documents

### 2.1 ASTM Standards:<sup>2</sup>

- D1193 Specification for Reagent Water
- D2699 Test Method for Research Octane Number of Spark-Ignition Engine Fuel
- D2700 Test Method for Motor Octane Number of Spark-Ignition Engine Fuel
- D4057 Practice for Manual Sampling of Petroleum and Petroleum Products
- D4175 Terminology Relating to Petroleum Products, Liquid Fuels, and Lubricants
- D4177 Practice for Automatic Sampling of Petroleum and Petroleum Products
- D4814 Specification for Automotive Spark-Ignition Engine Fuel
- D6299 Practice for Applying Statistical Quality Assurance and Control Charting Techniques to Evaluate Analytical Measurement System Performance
- D5842 Practice for Sampling and Handling of Fuels for Volatility Measurement
- D6300 Practice for Determination of Precision and Bias Data for Use in Test Methods for Petroleum Products and Lubricants
- D6624 Practice for Determining a Flow-Proportioned Average Property Value (FPAPV) for a Collected Batch of Process Stream Material Using Stream Analyzer Data
- D7453 Practice for Sampling of Petroleum Products for Analysis by Process Stream Analyzers and for Process Stream Analyzer System Validation
- E29 Practice for Using Significant Digits in Test Data to Determine Conformance with Specifications
- E177 Practice for Use of the Terms Precision and Bias in ASTM Test Methods
- E456 Terminology Relating to Quality and Statistics

### 2.2 Waukesha CFR Engine Manuals:

- CFR F-1 & F-2 Octane Rating Units Operation & Maintenance FORM 847<sup>3</sup>

## 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, (2) an assigned value, based on experimental work of some national or international organization, or (3) a consensus value, based on collaborative experimental work under the auspices of a scientific or engineering group. **E456/E177**

#### 3.1.1.1 Discussion—

In the context of this test method, accepted reference value is understood to apply to standard fuel or check fuel average research or motor octane numbers determined under reproducibility conditions by a recognized exchange testing organization having a minimum of 16 participants.

3.1.2 *analytical measurement system, n*—a collection of one or more components or subsystems, such as a sampler, test equipment, instrumentation, display devices, data handler, and printout or output transmitters that is used to determine a quantitative value of a specific property for an unknown sample. **D6299**

#### 3.1.2.1 Discussion—

In the context of this test method, the analytical measurement system is comprised of the knock testing unit, automated analyzer system, and any auxiliary equipment required for the safe operation of the engine.

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 machine surface of the crankcase. **D2699/D2700**

3.1.4 *determinability, n*—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; it is defined as that difference between two such single determined values as would be exceeded in the long run in only one case in 20 in the normal and correct operation of the test method. **D6300**

3.1.5 *detonation meter, n*—for knock testing, the signal conditioning instrument that accepts the electrical signal from the detonation pickup and provides an output signal for display. **D2699/D2700**

<sup>2</sup> For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

<sup>3</sup> The sole source of supply of the apparatus known to the committee at this time is Waukesha Engine Division, Dresser Equipment Group, Inc., 1000 W. St. Paul Avenue, Waukesha, WI 53188. Waukesha Engine Division also has CFR engine authorized sales and service organizations in selected geographical areas. If you are aware of alternative suppliers, please provide this information to ASTM International Headquarters. Your comments will receive careful consideration at a meeting of the responsible technical committee,<sup>1</sup> which you may attend.

3.1.6 *detonation pickup*, *n*—for knock testing, 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. **D2699/D2700**

3.1.7 *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. **D2699/D2700**

3.1.8 *fuel-air ratio for maximum knock intensity*, *n*—for knock testing, that proportion of fuel to air which produces the highest knock intensity for each fuel in the knock testing unit, provided this occurs within the specified carburetor fuel level limits. **D2699/D2700**

#### 3.1.8.1 Discussion—

In the context of this test method, the fuel-air ratio for maximum knock intensity can be determined manually or by the automated analyzer system.

3.1.8.1 *dynamic fuel-air ratio for maximum knock*, *n*—for knock testing, the changing of the mixture of fuel and air for engine combustion determined by continually varying fuel level in the carburetor delivery components, through the maximum knock intensity so that the observed peak knock intensity value can be selected as maximum knock intensity reading.

3.1.8.2 *equilibrium fuel-air ratio for maximum knock*, *n*—for knock testing, the changing of the mixture of fuel and air for engine combustion determined by making incremental step changes in fuel-air ratio, observing the equilibrium knock intensity for each step and selecting the fuel-air ratio which produces the highest knock meter reading.

3.1.9 *guide tables*, *n*— for knock testing, the specific relationship between cylinder height (compression ratio) and octane number at standard knock intensity. **D2699/D2700**

3.1.10 *knock*, *n*—in a spark-ignition engine, abnormal combustion, often producing audible sound, caused by auto-ignition of the air/fuel mixture. **D4175**

3.1.11 *knock intensity*, *n*—for knock testing, a measure of the level of knock. **D2699/D2700**

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. **D2699/D2700**

#### 3.1.12.1 Discussion—

In the context of this test method, the knock intensity signal may also be displayed using digital or recording instrumentation.

3.1.13 *motor octane number*, *n*—for spark-ignition engine fuel, the numerical rating of knock resistance obtained by comparison of the fuel's knock intensity with that of primary reference fuel blends when both are tested in a standardized CFR engine operating under the conditions specified in Test Method **D2700**.

3.1.14 *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. **E456**

#### 3.1.14.1 Discussion—

In the context of this test method, application of repeatability conditions is primarily applied to the determination of variability of delta octane numbers generated by repeating the comparison measurements within a short time, by the same operator, using the same comparator, on the same fuel pair.

3.1.15 *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. **E456**

3.1.16 *research octane number*, *n*—for spark-ignition engine fuel, the numerical rating of knock resistance obtained by comparison of the fuel's knock intensity with that of primary reference fuel blends when both are tested in a standardized CFR engine operating under the conditions specified in Test Method **D2699**.

3.1.17 *spread*, *n*—in knock measurement, the sensitivity of the detonation meter expressed in knockmeter divisions per octane number. **D2699/D2700**

3.1.18 *site assigned value*, *n*—a value that serves as an agreed-upon reference for comparison, determined from multiple test results obtained under site precision conditions.

#### 3.1.18.1 Discussion—

In the context of this test method, site assigned value is understood to apply to prototype fuel average research or motor octane number determined under site precision conditions using direct comparison delta octane number cycles comparing the prototype fuel to a standard fuel having an accepted reference value octane number.

3.1.19 *site precision conditions, n*—conditions under which test results are obtained by one or more operators in a single location practicing the same test method on a single measurement system using test specimens taken at random from the same sample of material over an extended period of time spanning at least a 15 day interval. **D6299**

#### 3.1.19.1 *Discussion*—

In the context of this test method, application of site precision conditions is primarily applied to the determination of the variability of delta octane average results, obtained by different operators, over different days, for the same fuel pair, using the same comparator. Each delta octane average result is obtained from repetitive comparisons of the same fuel pair under repeatability conditions.

3.1.20 *stream sample, n*—the material to be evaluated by an analytical measurement system, typically drawn from a flowing stream of either blended spark-ignition engine fuel or process unit material.

#### 3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *comparison reference fuel, n*—for direct comparison knock testing, a spark-ignition engine fuel having an assigned octane number that is the reference for the determination of the delta octane number of stream samples.

3.2.1.1 *standard fuel, n*—for direct comparison knock testing, a spark-ignition engine fuel having an octane number accepted reference value ( $RON_{ARV}$  or  $MON_{ARV}$ ) which is used as a secondary comparison reference fuel for (1) determination of the octane number site assigned value ( $RON_{SAV}$  or  $MON_{SAV}$ ) of prototype fuels, (2) determination of the  $\Delta O.N.$  of a stream sample, or (3) pairing with another standard fuel for analytical measurement system qualification checkout.

3.2.1.2 *prototype fuel, n*—for direct comparison knock testing, a spark-ignition engine fuel or process unit material having an octane number site assigned value ( $RON_{SAV}$  or  $MON_{SAV}$ ) referenced to an appropriate standard fuel, which is used as a tertiary comparison reference fuel for determination of the  $\Delta O.N.$  of a stream sample.

3.2.2 *delta octane number, n*—for direct comparison knock testing, the algebraic difference in octane number between two fuels under research or motor engine conditions, when determined by the direct comparison technique.

3.2.3 *paired check fuels (A and B), n*—for on-line knock testing system qualification checkout, two standard fuels used for system qualification checkout of an analytical measurement system.

3.2.3.1 *expected difference O.N., n*—for on-line knock testing system qualification checkout, the absolute octane number difference between paired check fuels (A–B) based on the  $O.N._{ARV}$  for both fuels.

3.2.4 *paired quality control fuels, n*—for on-line system quality control, a pair of fuels, one of which is a comparison reference fuel, to be used in the repetitive testing for  $\Delta O.N.$  as a quality control check of the analytical measurement system.

3.2.5 *span, n*—for direct comparison knock testing, a measure of the overall sensitivity of the analyzer. The ratio of the change in delta octane reported produced by a given change in either compression ratio or knock intensity.

#### 3.3 *Acronyms:*

3.3.1 *AMS*—analytical measurement system

3.3.2 *ARV*—accepted reference value

3.3.3  *$RON_{ARV}$* —research octane number accepted reference value

3.3.4  *$MON_{ARV}$* —motor octane number accepted reference value

3.3.5 *SAV*—site assigned value

3.3.6  *$RON_{SAV}$* —research octane number site assigned value

3.3.7  *$MON_{SAV}$* —motor octane number site assigned value

3.3.8 *C.R.*—compression ratio

3.3.9 *K.I.*—knock intensity

3.3.10 *O.N.*—octane number

3.3.11  *$\Delta O.N.$* —delta octane number

3.3.12 *PRF*—primary reference fuel

3.3.13 *CRF*—comparison reference fuel

#### 3.4 *Symbols:*

3.4.1 *Q*—accuracy qualification value

### 3.4.2 *K*—accuracy qualification acceptance limit

## 4. Summary of Test Method

4.1 The delta research ( $\Delta$ RON) or delta motor ( $\Delta$ MON) octane number of a stream sample is determined using a standard CFR engine operating under the appropriate test conditions, using an automated repetitive cycle that compares its knock characteristics with those of a comparison reference fuel (CRF) having an assigned octane number. The difference in knock characteristics may be measured as (1) the difference in knock intensity at constant compression ratio, or (2) the difference in compression ratio at constant knock intensity. The system draws the stream sample from a flowing stream and conditions it for delivery to the CFR engine carburetor. Comparison reference fuel is stored in a suitable container and is also appropriately conditioned for delivery to the CFR engine carburetor. System controls sequence the switching of the two fuels as well as monitoring all critical testing variables. The fuel-air ratio of each fuel is adjusted to produce the maximum knock intensity for that fuel.

## 5. Significance and Use

5.1 The delta octane number ( $\Delta$ O.N.) measure can quantify the difference of in-line blended spark-ignition engine fuel or process stream material octane number to a desired octane number to aid in optimizing control of blender facilities or refinery process units.

5.2 The  $\Delta$ O.N. measure, summed with a statistically sound comparison reference fuels O.N. provides either research or motor octane number value of the current in-line blended spark-ignition engine fuel or process stream material.

5.3 Through the use of cumulative flow-weighted averaging of the repetitive  $\Delta$ O.N. results, a statistically significant octane number can be assigned to a tender or batch of in-line blended spark-ignition engine fuel.

## 6. Interferences

6.1 Certain gases and fumes, which can be present in the area where the knock testing unit is located, may have a measurable effect on the  $\Delta$ O.N. 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 octane number of spark-ignition engine fuel 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  $\Delta$ O.N. obtained for spark-ignition engine fuels.

6.2.1 Electrical noise can affect the ability of the knock testing unit/automated analytical measurement system to accurately determine the  $\Delta$ O.N. of the sample stream fuel.

6.3 *Precaution*—Avoid exposure of sample fuels to sunlight or fluorescent lamp UV emissions to minimize induced chemical reactions that can affect octane number ratings.<sup>4</sup>

6.3.1 Exposure of these fuels to UV wavelengths shorter than 550 nanometers for a short period of time may significantly affect octane number ratings.<sup>4</sup>

## 7. Apparatus

7.1 This test method utilizes a multi-component analytical measurement system (AMS). It incorporates a knock testing engine with instrumentation to measure and produce an output signal representative of the difference in knock rating or  $\Delta$ O.N. An associated automated control system includes a fuel delivery system to introduce a stream sample or CRF to the engine critical carburetor components. The automated system shall also include equipment and controls for switching between the CRF and the stream sample, controls for operating the test engine and monitoring the critical operating conditions, and instrumentation to convert the compression ratio (C.R.) or knock intensity (K.I.) to a  $\Delta$ O.N.

7.1.1 An appropriate CFR engine knock testing unit specified for the determination of research octane number or motor octane number and meeting the recommendations of the manufacturer of the AMS. Specific knock testing unit equipment can include the following:

7.1.1.1 For research octane number measurement, a Model CFR F-1, single cylinder engine knock testing unit assembly comprised of the appropriate critical or equivalent equipment components selected by the system manufacturer, and for which specifications are provided in Test Method **D2699**, Annex A2.<sup>3</sup>

7.1.1.2 For motor octane number measurement, a Model CFR F-2, single cylinder engine knock testing unit assembly comprised of the appropriate critical or equivalent equipment components selected by the system manufacturer, and for which specifications are provided in Test Method **D2700**, Annex A2.<sup>3</sup>

<sup>4</sup> Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1502. Contact ASTM Customer Service at [service@astm.org](mailto:service@astm.org).



7.1.1.3 Instrumentation for the measurement of knock, temperatures or other knock testing unit variables as selected by the system manufacturer, and for which specifications are provided in Annex A2, of either Test Method **D2699** or Test Method **D2700**, whichever is appropriate.

7.1.1.4 The AMS system installation requires a number of components and devices to integrate the critical or equivalent equipment items into a complete working unit. Specific items to satisfy important criteria for proper operation of the respective CFR engine unit are to comply with the appropriate non-critical equipment specifications in Annex A2, of either Test Method **D2699** or Test Method **D2700**, whichever is appropriate.

7.1.1.5 Equipment for adjustment of engine compression ratio and a mechanism for relative measurement of this variable when the  $\Delta O.N.$  value is based on differences in engine compression ratio.

7.1.2 Automated control equipment for adjustment and monitoring of the critical operating variables of the knock testing unit is required and selected in accordance with the recommendations and instructions of the system manufacturer. Specific variables and conditions to be handled by the automated control equipment can include the following:

7.1.2.1 A mechanism to vary fuel-air ratio and determine the condition that produces a maximum K.I. signal. Determination of the fuel-air ratio for maximum knock intensity can be performed using either the equilibrium or a dynamic search technique.

7.1.2.2 An adjustable octane number scaling function to convert the measured signal variable to an output signal  $\Delta O.N.$  value, recognizing any non-linear relationship that can exist.

7.1.2.3 Timing controls for fuel switching and measurement functions to meet the specified operating principles of this test method.

7.1.2.4 Suitable sensors for monitoring operating conditions and system safety related functions that are incorporated in the system design.

7.1.3 A sample system to provide a continuously representative stream and deal with the unconsumed stream sample.

7.1.3.1 Equipment to treat the incoming stream sample fuel to remove particulate matter and entrained water to meet the requirements specified by the system manufacturer.

7.1.4 Storage vessels and associated equipment for storing and supplying one or more CRF materials.

## 8. Reagents and Reference Materials

8.1 *Cylinder Jacket Coolant*—Use water in the cylinder jacket for engine locations where the resultant boiling temperature will be  $100 \pm 1.5^\circ\text{C}$  ( $212 \pm 1.5^\circ\text{C}$  ( $212^\circ\text{F} \pm 3^\circ\text{F}$ ),  $3^\circ\text{F}$ ). Use water with commercial glycol based antifreeze added in sufficient quantity to meet the boiling temperature requirements where altitude dictates. A commercial multifunction water treatment material can be used in the coolant to minimize corrosion and mineral scale that can alter heat transfer and rating results.

8.1.1 Water is understood to mean reagent water conforming to type IV, Specification **D1193**. (**Warning**—Ethylene glycol based antifreeze is poisonous and may be harmful or fatal if inhaled or swallowed. See **Annex A1**.)

8.2 *Engine Crankcase Lubricating Oil*—SAE 30 viscosity grade oil meeting the current API service classification for spark-ignition engines containing a detergent additive and having a kinematic viscosity of  $9.39$  to  $12.5$   $\text{mm}^2$  per s (cst) at  $100^\circ\text{C}$  ( $212^\circ\text{F}$ ) and a viscosity index of not less than 85. Do not use oils containing viscosity index improvers or multigrade oils. (**Warning**—Lubricating oil is combustible and its vapor is harmful. See **Annex A1**.)

8.3 *Standard Fuel*—(**Warning**—Standard fuel is flammable and its vapors are harmful. Vapors may cause flash fire. See **Annex A1**.) A secondary comparison reference fuel that conforms to the following:

8.3.1 *Octane Number*—Selected to have a  $RON_{ARV}$  or  $MON_{ARV}$  with respect to the O.N. of the prototype fuel or the stream samples to be analyzed.

8.3.1.1 The difference between standard fuel and related prototype fuel shall not exceed  $\pm 0.5$  O.N.

8.3.1.2 The difference between standard fuel and the stream samples to be analyzed shall not exceed  $\pm 1.0$  O.N.

(1) *Discussion*—The difference between the standard fuel and the stream sample refers to when the standard fuel is used in direct comparison to the stream sample.

8.3.1.3 Determine the appropriate  $O.N._{ARV}$  of standard fuel under reproducibility conditions using a minimum of 16 different exchange participants (see **Annex A3**).

8.3.2 *Volatility*—Or use with blended stream samples, the standard fuel can be slightly less volatile than the stream samples to be analyzed in the interest of minimizing weathering.

8.3.2.1 A vapor pressure, as defined in Test Method **D4814**, of less than  $68.9$  kPa ( $10$  psi) is preferred but, in any case, it shall not exceed  $82.7$  kPa ( $12$  psi).

8.3.3 *Hydrocarbon Composition*—Similar to that of a related prototype fuel or the stream samples to be analyzed. Users are cautioned to investigate the O.N. effect of any significant differences in composition matrix between these related fuels.

8.3.4 *Antiknock Compound*—The same organometallic lead or manganese additive compound, in a similar concentration, shall be present in the standard fuel if it is present in the prototype fuel or stream sample to be analyzed.

8.3.5 *Octane Enhancers*—Compounds such as oxygenates shall be present in the standard fuel, in similar concentration, to that present in the prototype fuel or stream sample to be analyzed.

8.3.6 *Antioxidant*—Add at the treat-rate recommended by the additive supplier to ensure maximum storage stability.

8.3.6.1 Add antioxidant prior to distribution of standard fuel for the determination of the  $O.N._{ARV}$ .

8.3.7 *Metal Deactivator*—Add in accordance with supplier recommendations if it is deemed necessary.

8.3.8 *Storage and Handling*—Controlled conditions to minimize the possibility of octane number change or contamination. Systems and procedures shall conform to the requirements set forth in **Annex A2** of this test method.

8.4 *Prototype Fuel*—(**Warning**—Prototype fuel is flammable and its vapors are harmful. Vapors may cause flash fire. See **Annex A1**.) A tertiary comparison reference fuel that conforms to the following:

8.4.1 *Octane Number*—The difference between prototype fuel and the stream samples to be analyzed shall not exceed  $\pm 1.0$  O.N.

8.4.1.1 Determine the appropriate O.N.<sub>SAV</sub> of prototype fuel based on the average value of a minimum of 10 direct match knock characteristic comparisons, obtained either manually or automatically, under site precision conditions (see **Annex A4**).

8.4.2 *Volatility*—For use with blended stream samples, the prototype fuel can be slightly less volatile than the stream samples to be analyzed in the interest of minimizing weathering.

8.4.2.1 A vapor pressure, as defined in Test Method **D4814**, of less than 68.9 kPa (10 psi) is preferred but, in any case, it shall not exceed 82.7 kPa (12 psi).

8.4.3 *Hydrocarbon Composition*—Similar to that of the stream samples to be analyzed. Users are cautioned to investigate the O.N. effect of any significant differences in composition matrix between these related fuels.

8.4.4 *Antiknock Compound*—The same organometallic lead or manganese additive compound, in a similar concentration, shall be present in the prototype fuel if it is present in the stream sample to be analyzed.

8.4.5 *Octane Enhancers*—Compounds such as oxygenates shall be present in the prototype fuel, in similar concentration, to that present in the stream sample to be analyzed.

8.4.6 *Antioxidant*—Add at the treat-rate recommended by the additive supplier to ensure maximum storage stability.

8.4.7 *Metal Deactivator*—Add in accordance with supplier recommendations if it is deemed necessary.

8.4.8 *Storage and Handling*—Control conditions to minimize the possibility of octane number change or contamination. Systems and procedures shall conform to the recommendations set forth in **Annex A2**.

8.5 *Paired Check Fuels*—The paired check fuels will have an expected difference O.N. ranging from 0.2 to 1.0 and be coded so the difference in the accepted reference values (Fuel A–Fuel B) is a positive value.

8.5.1 The fuel characteristics, including those for antiknock compound, octane enhancers, and antioxidant protection are to be similar for the two check fuels of a pair.

8.6 *Paired Quality Control Fuels*—The two quality control fuels, one of which is a comparison reference fuel, shall have  $\Delta$ O.N. ranging from 0.2 to 1.0.

8.7 *Primary Reference Fuels*—Reference fuel grade *isooctane*, heptane, the 80 O.N. blend of the two meeting the specifications given in Test Method **D2699** or Test Method **D2700**, or both. (**Warning**—Primary reference fuels are flammable and the vapors are harmful. Vapors may cause flash fire. See **Annex A1**.)

## 9. Sampling

9.1 Collect stream samples for on-line analysis in accordance with Practice **D4177** or **D7453**.

9.1.1 Collect, treat, and deliver stream samples to the CFR engine carburetor in a way that minimizes exposure to light of any form.

9.2 Collect stream sample material for preparation, storage and laboratory testing as comparison reference fuels in accordance with Practices **D4057**, **D4177**, and **D5842**.

9.2.1 Collect and store sample fuels in an opaque container, such as a dark brown glass bottle, metal can, or a minimally reactive plastic container to minimize exposure to UV emissions from sources such as sunlight or fluorescent lamps.

## 10. Basic Engine and Instrument Settings and Operating Conditions

10.1 *Standard Operating Conditions:*

10.1.1 *Installation of CFR Engine Equipment and Instrumentation*—Place the CFR engine on a suitable foundation and hook up all utilities in accordance with the specifications of the engine manufacturer. Assemble the supplemental automated analyzer system and fuel delivery system components in accordance with the instructions of the system manufacturer. All installation aspects are to comply with local and national codes and installation requirements.

10.1.2 Proper operation of the CFR engine requires assembly of a number of engine components and adjustment of a series of engine variables to prescribed specifications. These settings and adjustments are specified in the CFR F-1 & F-2 Octane Rating Unit Operation & Maintenance Manual and in the Basic Engine and Instrument Settings And Standard Operating Conditions sections of Test Method **D2699** or Test Method **D2700**, or both, and are of the following types:

10.1.2.1 Conditions based on component specifications (**Annex A2** and **A3** of Test Method **D2699** or Test Method **D2700**, or both).

10.1.2.2 CFR engine assembly settings and operating conditions.

10.1.2.3 Proper operation of the automated analyzer system equipment and instrumentation.

10.2 *CFR Engine Assembly Settings and Operating Conditions:*

10.2.1 *Compensation of Compression Ratio for Standard Knock Intensity*—Knock testing engines operating at sites where the barometric pressure is lower or higher than 29.92 in. Hg, standard pressure, will knock softer or harder respectively than the engines operating at standard pressure. To compensate for this effect, the engine compression ratio is adjusted proportional to the difference between the site median and standard barometric pressure. The range of barometric pressure experienced at any testing location is generally less than ~~4.5 in.~~ 1.5 in. Hg and the compression ratio compensation to cause essentially standard knock intensity at the location can be achieved using a fixed offset based on median barometric pressure for the site. This compensation can be made once by setting the offset between the two dials of the digital counter and using the compensated digital counter reading for the  $\Delta$ O.N. measurement.

10.2.1.1 Determine the range of barometric pressure that typically occurs at the site for the year and calculate the median barometric pressure. If there are significant seasonal differences, it may be appropriate to calculate the median barometric pressure for each season.

10.2.1.2 Using the median barometric pressure and Table A4.4 or A4.5 of Test Method D2699 for research octane number units and Table A4.9 or A4.10 of Test Method D2700 for motor octane number units determine the compensation for guide table cylinder height (digital counter reading).

10.2.1.3 Set the digital counter so that the lower dial reading is compensated for the site median difference in barometric pressure from the 29.92 in. Hg standard pressure.

10.2.2 *Selecting and Setting Compression Ratio for On-line Operation*—On-line  $\Delta$ O.N. measurement for a given pair of fuels is initiated by setting the engine compression ratio to the guide table digital counter reading that corresponds to the appropriate CRF assigned octane number from the tables in Annex A4 in Test Method D2699 or Test Method D2700, whichever is appropriate, for the AMS.

10.2.2.1 For systems that operate at a constant C.R., the barometric pressure at the site may change slightly with time and this will result in minor shifts in engine K.I. level. If the K.I. on the comparison reference fuel trends below 35 or above 65 the AMS may be taken off-line, for a short period of time, to reset the K.I. to 50 by adjusting the detonation meter -METER READING- dial before continuing on-line analysis.

10.2.2.2 For systems that operate at a constant K.I. by adjustment of compression ratio the barometric pressure at the site may change slightly with time and this will result in minor shifts in the digital counter reading. If the digital counter reading for the reference fuel trends more than 20 units, the AMS may be taken off-line, for a short period of time, to reset the K.I. to 50 at the CRF O.N. digital counter reading by adjusting the detonation meter -METER READING- dial before continuing on-line.

10.2.2.3 Typical minor shifts in either knock intensity or digital counter reading affect each of the fuels under test in the same manner and these shifts do not significantly affect the  $\Delta$ O.N. measurement.

10.2.3 *Span Determination and Adjustment*—The span setting for the analyzer is critical for the accurate determination of  $\Delta$ O.N. The engine spread for constant C.R. systems or adherence to guide table readings for constant K.I. systems at the octane range of the standard or prototype fuel must be accurately determined and reflected in the analyzer span.

10.2.3.1 For AMS operating at a constant compression ratio, the span setting (K.I./octane) is to be determined by the running of two PRF fuels with a difference of  $1.0 \pm 0.2$  O.N. on the analyzer as per the manufacturer's instructions. The difference between the two fuels' K.I. readings divided by the difference in the two fuels' O.N. will give the spread for engine at that octane. The spread for the engine at the octane range of the PRFs will then need to be entered into the analyzer software as the span per the manufacturer's instructions.

10.2.3.2 For AMS operating at a constant knock intensity the span setting (C.R./octane) is to be determined by the running of two PRF fuels with a difference of  $1.0 \pm 0.2$  O.N. on the analyzer as per the manufacturer's instructions. The difference in the C.R. between the two fuels divided by the difference O.N. will give the span for the engine at that octane. The span for the engine at the octane range of the PRFs will then need to be entered into the analyzer software as per the manufacturer's instructions.

10.2.4 *Fuel-Air Ratio Characteristic*—With the engine operating at a cylinder height that causes knock, variation of the fuel-air mixture has a characteristic effect, typical for all fuels. This test method specifies that each stream sample and CRF shall be operated at the fuel-air ratio that produces the maximum K.I. To maintain good fuel vaporization, a restrictive orifice or horizontal jet is utilized so that the maximum knock condition occurs for fuel levels between 0.7 and 1.7 in. referenced to the centerline of the carburetor venturi. The mechanics for varying the fuel mixture can be accomplished using various approaches.

10.2.4.1 *Fixed Horizontal Jet—Variable Fuel Level System*—Fuel level adjustments are made by varying the float reservoir in incremental steps. Selection of a horizontal jet having the appropriate orifice size establishes the fuel level at which a typical sample fuel achieves maximum knock.

10.2.4.2 *Fixed Fuel Level—Variable Orifice System*—A fuel reservoir, in which the fuel can be maintained at a prescribed constant level, supplies an adjustable orifice (special long-tapered needle valve) used in place of the horizontal jet. Fuel mixture is changed by varying the needle valve position. Typically, the constant fuel level selected is near the 1.0 level, which satisfies the fuel level specification.

10.2.4.3 *Dynamic or Falling Level System*—A fuel reservoir, filled to a higher level than that required for maximum K.I., delivers fuel through either a fixed bore or adjustable horizontal jet. With the engine firing, the fuel level falls as fuel is consumed. Fuel level changes at a specifically selected rate that is established by the cross-sectional area of the fuel reservoir and associated sight glass assembly. Maximum K.I. is recorded as the fuel level passes through the critical level.



### 10.2.5 Intake Air and Mixture Temperature Setting Practices:

#### 10.2.5.1 Motor Method:

(1) Intake Air Temperature— $383.8\text{ °C} \pm 2.8\text{ °C}$  ( $1002.8\text{ °C}$  ( $100\text{ °F} \pm 5\text{ °F}$ ),  $5\text{ °F}$ ).

(2) Intake Mixture Temperature— $149.149\text{ °C} \pm 1\text{ °C}$  ( $300.1\text{ °C}$  ( $300\text{ °F} \pm 2\text{ °F}$ ),  $2\text{ °F}$ ) maintained within  $1\text{ °C}$  ( $\pm 2\text{ °F}$ )  $1\text{ °C}$  ( $\pm 2\text{ °F}$ ) when C.R. or K.I. results used for a delta octane measurement are recorded.

#### 10.2.5.2 Research Method:

(1) Intake Air Temperature— $525.2\text{ °C} \pm 1\text{ °C}$  ( $125.1\text{ °C}$  ( $125\text{ °F} \pm 2\text{ °F}$ ),  $2\text{ °F}$ ) is specified for operation at standard barometric pressure of 101.0 kPa (29.92 in. Hg). IATs for other than standard barometric pressure conditions need to be adjusted to compensate for the site median barometric pressure.

(2) Determine the site median barometric pressure (see details previously given under Site Compensation of Compression Ratio for Standard Knock Intensity).

(3) Use the site median barometric pressure and Table A4.4 or A4.5 of Test Method **D2699** to determine the applicable intake air temperature.

(4) Adjust analyzer measurement system settings to deliver the compensated intake air temperature and this temperature shall then be maintained within  $\pm 1\text{ °C}$  ( $\pm 2\text{ °F}$ )  $\pm 1\text{ °C}$  ( $\pm 2\text{ °F}$ ) when C.R. or K.I. results used for a delta octane measurement are recorded.

### 10.3 Proper Operation of the Automated Analyzer System Equipment and Instrumentation:

#### 10.3.1 Sample Stream Sampling Systems:

10.3.1.1 Cyclic and Continuous Fuel Sampling Techniques—AMS can determine the knock characteristic measurement using either a grab sample or continuously flowing sample.

10.3.1.2 For the continuously flowing sample approach, fuel is continuously delivered to the CFR engine carburetor while knock measurement is in progress, and any unconsumed fuel is removed from the AMS.

10.3.1.3 For the intermittent or grab sample approach, a carburetor device isolates a portion of either the stream sample or CRF, then performs the knock measurement sequence on that sample.

10.3.1.4 The system needs to operate on each fuel for a minimum of 4 min. The time periods spent on each fuel can be set based on engine operation and site requirements.

10.3.1.5 The system must be rating the sample stream for a minimum of 50 % of the cycle time.

10.3.2 Sample Temperature—Deliver the CRF and sample fuel to the knock-testing unit critical carburetor components at the same nominal temperature. This temperature shall be greater than  $0\text{ °C}$  ( $32\text{ °F}$ )  $0\text{ °C}$  ( $32\text{ °F}$ ) but not exceed  $10\text{ °C}$  ( $50\text{ °F}$ )  $10\text{ °C}$  ( $50\text{ °F}$ ).

10.3.3 System Alarm Functions—AMS systems for unattended operation utilize sensors, control logic, and other devices designed to protect the system and facilities from abnormal conditions. Some typical sensors are: low crankcase oil pressure, loss of jacket coolant, loss of sample stream pressure or flow, or both, excessive C.R. as evidenced by cylinder height limits, indication of system measurement instability as evidenced by out-of-limit repeatability measurements for comparison reference fuel, the presence of hydrocarbon vapors at the unit, the presence of carbon monoxide in the room atmosphere, and so forth. Some alarm functions are active and result in system shutdown. Other alarms are passive and simply indicate an operating characteristic that is out of performance limits.

## 11. System Qualification Checkout

11.1 Check the performance of the AMS at intervals in accordance with the user quality system or after any maintenance that could affect measurement system performance. Operate the system using paired check fuels to determine whether it produces the correct  $\Delta\text{O.N.}$  value and does so with appropriate system stability.

11.1.1 The  $\Delta\text{O.N.}$  value is dependent upon (1) knock testing unit sensitivity, (2) detonation meter sensitivity, and (3) automated analyzer span setting for the octane range to be used.

11.1.2 The knock testing unit must be able to repeatedly measure the  $\Delta\text{O.N.}$  for two fuels of different octane number. The latitude of engine condition is quite broad and when the knock testing unit is no longer satisfactory for automated analyzer operation it will be evidenced as instability of knock intensity. This condition often can be rectified through carbon blasting and ultimately by cylinder overhaul.

11.1.3 Set the span according to the manufacturer's instructions for the desired octane range so that the knock intensity or compression ratios can be used to accurately calculate the  $\Delta\text{O.N.}$

11.2 Perform the qualification checkout with the AMS operating under standard conditions as specified in this method. Equal time periods of operation for each of the paired check fuels shall be used. The time period for operation on each fuel shall be 4 min or longer.

11.2.1 Sequence the AMS between the paired check fuels until a minimum of six cycles has completed. A complete cycle comprises one period of operation on one fuel (A), followed by one period on the second fuel (B). Sequence the check fuels to the analyzer measurement system so that the  $\Delta\text{O.N.}$  values are determined by subtracting the fuel B result from the fuel A result.

#### 11.3 Determination of Average $\Delta\text{O.N.}$ :

- 11.3.1 Discard the  $\Delta$ O.N. result for the first complete cycle determination.
- 11.3.2 Tabulate the remaining  $\Delta$ O.N. values (Fuel B from Fuel A), including the proper algebraic sign.
- 11.3.3 Calculate the average  $\Delta$ O.N., with respect to algebraic sign.

11.4 *System Accuracy Qualification:*

11.4.1 Assess the accuracy of the system by comparing the measured average  $\Delta$ O.N. for the paired check fuels to the expected difference O.N.

11.4.1.1 Calculate  $Q$ , the accuracy qualification value, using the following formula:

$$Q = \text{measured average } \Delta\text{O.N.} - \text{expected difference O.N.}$$

11.4.1.2 Use **Table 1** to determine if the calculated  $Q$  value is within the accuracy qualification acceptance limit,  $K$ , for the applicable test method operating conditions (RON or MON).

11.4.1.3 The calculated  $Q$  value would, in the long run, in the normal and correct operation of this test method, fall outside the accuracy qualification acceptance limits ( $K$ ) in only 1 case in 20.

11.4.1.4 If  $Q$  is within the limits of  $K$  for the respective test method, AMS is considered to be acceptably accurate.

11.4.1.5 If  $Q$  is outside the limits of  $K$  for the respective test method, the system is considered to be inaccurate and evaluation is required to identify and correct the root cause(s) of the inaccuracy before the system is used for  $\Delta$ O.N. ratings of stream samples.

11.5 *System Stability Assessment:*

11.5.1 Assess the stability of the system by comparing the  $\Delta$ O.N. range value for the paired check fuels data to the Range Limit ( $L$ ) in **Table 2** for the respective test method.

NOTE 1—Range limit ( $L$ ) values listed in **Table 2** are for use with data sets of five independent  $\Delta$ O.N. determinations and infer a Type 1 error of approximately 1 %.

11.5.1.1 Calculate the range value, using the following formula:

$$\text{Range value} = \text{maximum measured } \Delta\text{O.N.} - \text{minimum measured } \Delta\text{O.N.}$$

11.5.1.2 If the  $\Delta$ O.N. range value is less than the range limit ( $L$ ) for the respective test method, AMS is considered to be acceptably stable.

11.5.1.3 If the  $\Delta$ O.N. range value is greater than the range limit ( $L$ ) for the respective method operating conditions, the system is considered to be unstable. Evaluation is required to identify and correct the root cause(s) of the instability before the system is used for  $\Delta$ O.N. ratings of stream samples.

## 12. Procedure

12.1 Detailed operating procedures shall conform to the recommendations of the AMS manufacturer.

## 13. Calculation of Delta Octane Number and Octane Number

13.1  $\Delta$ O.N. calculation involves taking the signed difference in knock intensity or compression ratio signals between the reference fuel (standard or prototype) and the stream sample fuel and then dividing it by the appropriate span.

13.1.1 *Differential Knock Intensity at a Constant Compression Ratio:*

$$\Delta\text{O.N.} = (\text{K.I. reference} - \text{K.I. sample}) / \text{Span (K.I./octane)}$$

Example:

K.I. Reference Fuel = 50

K.I. sample fuel = 57

Span (K.I./Octane) = 20

$\Delta$ O.N. = (50-57) / 20

$\Delta$ O.N. = -0.35

13.1.2 *Differential Compression Ratio at a Constant Knock Intensity:*

$$\Delta\text{O.N.} = (\text{C.R. sample} - \text{C.R. reference}) / \text{Span (C.R./octane)}$$

Example:

Reference Fuel C.R. = 756

Sample Fuel C.R. = 764

**TABLE 1 Accuracy Qualification Acceptance Limit Values,  $K$**

Test Method	Accuracy Qualification Acceptance Limit
Research	$\pm 0.4$
Motor	$\pm 0.4$