



Standard Test Method for Determination of Derived Cetane Number (DCN) of Diesel Fuel Oils—Fixed Range Injection Period, Constant Volume Combustion Chamber Method¹

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1. Scope*

1.1 This test method covers the quantitative determination of the ignition characteristics of conventional diesel fuel oils, diesel fuel oils containing cetane number improver additives, and is applicable to products typical of Specification **D975**, Grades No. 1-D and 2-D regular and low-sulfur diesel fuel oils, European standard EN 590, and Canadian standards CAN/CGSB-3.517-2000 and CAN/CGSB 3.6-2000. The test method may also be applied to the quantitative determination of the ignition characteristics of blends of fuel oils containing bio-diesel material, and diesel fuel oil blending components.

1.2 This test method measures the ignition delay and utilizes a constant volume combustion chamber with direct fuel injection into heated, compressed air. An equation converts an ignition delay determination to a derived cetane number (DCN).

1.3 This test method covers the ignition delay range from a minimum value of 35.0 DCN (ignition delay of 4.89 ms) to a maximum value of 59.6 DCN (ignition delay of 2.87 ms). The average DCN result for each sample in the ILS ranged from 37.29 (average ignition delay of 4.5894 ms) to 56.517 (average ignition delay of 3.0281 ms).

1.4 The values stated in SI units are to be regarded as standard. No other units of measurement are included in this standard.

1.5 *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.*

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

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2. Referenced Documents

2.1 *ASTM Standards*:²

- D613** Test Method for Cetane Number of Diesel Fuel Oil
- D975** Specification for Diesel Fuel Oils
- D1193** Specification for Reagent Water
- D4057** Practice for Manual Sampling of Petroleum and Petroleum Products
- D4175** Terminology Relating to Petroleum, Petroleum Products, and Lubricants
- D4177** Practice for Automatic Sampling of Petroleum and Petroleum Products
- D5854** Practice for Mixing and Handling of Liquid Samples of Petroleum and Petroleum Products
- D6299** Practice for Applying Statistical Quality Assurance and Control Charting Techniques to Evaluate Analytical Measurement System Performance
- D6300** Practice for Determination of Precision and Bias Data for Use in Test Methods for Petroleum Products and Lubricants
- D6708** Practice for Statistical Assessment and Improvement of Expected Agreement Between Two Test Methods that Purport to Measure the Same Property of a Material
- E456** Terminology Relating to Quality and Statistics
- E832** Specification for Laboratory Filter Papers

2.2 *EN Standard*:³

- EN 590** Automotive Fuels—Diesel—Requirements and Test Methods

2.3 *Energy Institute Standard*:⁴

- IP 41** Ignition Quality of Diesel Fuels—Cetane Engine Test Method

² 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.

³ Available from European Committee for standardization. Central Secretariat: rue de Stassart, 36, B-1050 Brussels, Belgium.

⁴ Available from Energy Institute, 61 New Cavendish St., London, WIG 7AR, U.K.

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

2.4 Canadian Standards:⁵

CAN/CGSB-3.517-2000 Regular Sulphur Diesel Fuel—Specification

CAN/CGSB 3.6-2000 Automotive Low-Sulphur Diesel Fuel—Specification

2.5 DIN Standard:⁶

DIN 73372 Einspritzdüsen Grösse T und U

3. Terminology

3.1 Definitions:

3.1.1 *accepted reference value (ARV)*, *n*—a value that serves as an agreed-upon reference for comparison and that 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, such as the U.S. National Institute of Standards and Technology (NIST), or (3) a consensus value, based on collaborative experimental work under the auspices of a scientific or engineering group. **E456**

3.1.1.1 *Discussion*—In the context of this method, accepted reference value is understood to apply to the ignition delay of specific reference materials determined under reproducibility conditions by collaborative experimental work.

3.1.2 *biodiesel*, *n*—fuel comprised of mono-alkyl esters of long chain fatty acids derived from vegetable oils or animal fats, designated B100.

3.1.3 *biodiesel blend (BXX)*, *n*—blend of biodiesel fuel with diesel fuel oils.

3.1.3.1 *Discussion*—In the abbreviation, BXX, the XX represents the volume percentage of biodiesel fuel in the blend.

3.1.4 *cetane number (CN)*, *n*—a measure of the ignition performance of a diesel fuel oil obtained by comparing it to reference fuels in a standardized engine test. **D4175**

3.1.4.1 *Discussion*—In the context of this method, cetane number is that defined by ASTM **D613/IP 41**.

3.1.5 *check standard*, *n*—in *QC testing*, a material having an accepted reference value used to determine the accuracy of a measurement system. **D6299**

3.1.5.1 *Discussion*—In the context of this test method, check standard refers to heptane.

3.1.6 *quality control (QC) sample*, *n*—for use in quality assurance programs to determine and monitor the precision and stability of a measurement system, a stable and homogeneous material having physical or chemical properties, or both, similar to those of typical samples tested by the analytical measurement system. The material is properly stored to ensure sample integrity, and is available in sufficient quantity for repeated, long term testing. **D6299**

3.2 Definitions of Terms Specific to This Standard:

3.2.1 *calibration reference material*, *n*—a pure chemical having an assigned ignition delay accepted reference value.

3.2.2 *charge air*, *n*—compressed air at a specified pressure introduced into the combustion chamber at the beginning of each test cycle.

3.2.3 *charge air temperature*, *n*—temperature, in °C, of the air inside the combustion chamber.

3.2.4 *combustion analyzer*, *n*—an integrated compression ignition apparatus to measure the ignition characteristics of diesel fuel oil.

3.2.5 *derived cetane number (DCN)*, *n*—a number calculated using a conversion equation to determine a cetane number.

3.2.5.1 *Discussion*—The conversion equation relates a measured ignition delay or ignition delay and combustion delay from a combustion analyzer to a cetane number.

3.2.6 *ignition delay (ID)*, *n*—that period of time, in milliseconds (ms), between the start of fuel injection and the start of combustion as determined using the specific combustion analyzer applicable for this test method.

3.2.6.1 *Discussion*—In the context of this test method, start of fuel injection is interpreted as the initial movement or lift of the injector nozzle needle as measured by a motion sensor; start of combustion is interpreted as that point in the combustion cycle when a significant (+0.02 MPa above chamber static pressure) and sustained increase in rate-of-change in pressure, as measured by a pressure sensor in the combustion chamber, ensures combustion is in progress.

3.2.7 *injection period (IP)*, *n*—the period of time, in milliseconds (ms), that the fuel injector nozzle is open as determined using the specific combustion analyzer applicable for this test method.

3.2.8 *operating period*, *n*—the time, not to exceed 12 h, between successive calibration or QC testing, or both, of the combustion analyzer by a single operator.

3.3 Acronyms:

3.3.1 *ARV*—accepted reference value

3.3.2 *CN*—cetane number

3.3.3 *DCN*—derived cetane number

3.3.4 *ID*—ignition delay

3.3.5 *QC*—quality control

4. Summary of Test Method

4.1 A small specimen of diesel fuel oil is injected into a heated, temperature-controlled constant volume chamber, which has previously been charged with compressed air. Each injection produces a single-shot, compression ignition combustion cycle. ID is measured using sensors that detect the start of fuel injection and the start of significant combustion for each cycle. A complete sequence comprises 2 preliminary cycles and 25 further cycles. The ID measurements for the last 25 cycles are averaged to produce the ID result. An equation converts the ID result to a DCN.

5. Significance and Use

5.1 The ID and DCN values determined by this test method can provide a measure of the ignition characteristics of diesel fuel oil in compression ignition engines.

⁵ Available from the Canadian General Standards Board, Ottawa, Canada, K1A 1G6.

⁶ Available from DIN, Deutsches Institut für Normung, Burggrafenstrasse 6, 10787 Berlin.

5.2 This test can be used by engine manufacturers, petroleum refiners and marketers, and in commerce as a specification aid to relate or match fuels and engines.

5.3 The relationship of diesel fuel oil DCN determinations to the performance of full-scale, variable-speed, variable-load diesel engines is not completely understood.

5.4 This test may be applied to non-conventional fuels. It is recognized that the performance of non-conventional fuels in full-scale engines is not completely understood. The user is therefore cautioned to investigate the suitability of ignition characteristic measurements for predicting performance in full-scale engines for these types of fuels.

5.5 This test determines ignition characteristics and requires a sample of approximately 220 mL and a test time of approximately 20 min on a fit-for-use instrument.

6. Interferences

6.1 **Warning**—Minimize exposure of sample fuels, calibration reference materials, QC samples, and check standard to sunlight or fluorescent lamp UV emissions to minimize induced chemical reactions that can affect ignition delay measurements.⁷

6.1.1 Exposure of these fuels and materials to UV wavelengths shorter than 550 nm for a short period of time can significantly affect ignition delay measurements.

NOTE 1—The formation of peroxide and radicals can affect ignition delay measurement. These formations are minimized when the sample or material is stored in the dark in a cold room at a temperature of less than 10°C and covered by a blanket of nitrogen.

7. Apparatus

7.1 **General**—This test method uses an integrated automated analytical measurement system⁸ (see Fig. 1) comprised of:

7.1.1 **Combustion Chamber**—A cylindrical block having a volume of 0.60 ± 0.03 L, with external heating elements, heat shield, and electrically actuated intake and exhaust valves. There is an opening at one end of the chamber to accommodate insertion of the fuel injection nozzle assembly and an opening at the other end of the chamber to accommodate insertion of intake, exhaust, and various sensors.

7.1.2 **Fuel Injection System**—A pneumatically actuated fuel injection system with fuel injection pump, injector nozzle assembly and associated sample reservoir to assure for proper and repeatable injection of calibration, QC material, and test specimens into the combustion chamber. The system includes:

7.1.2.1 **Fuel Sample Reservoir**—A metal reservoir having a nominal volume of 100 mL.

7.1.2.2 **Fuel Injector Nozzle**—A standard one-hole nozzle conforming to the requirements of DIN 73372. The nozzle is assembled to the body that incorporates a spring-loaded needle extension with screw and lock nut for adjusting the nozzle opening pressure setting; a fuel bleed passage connecting to an external bleed valve for bleeding fuel from the nozzle and nozzle body; and a positions motion sensor mounted in an adjustable housing near the injector nozzle needle extension pin, to determine when the nozzle needle lifts to initiate the start of injection.

7.1.3 **Coolant System**—A closed-loop circulating coolant system to control the temperature of the combustion injector nozzle. The system includes an auxiliary heat exchanger with built-in circulating pump and flow control valves.

7.1.4 **Instrument Sensors**—Sensors used to measure and either indicate the value of a variable or transmit the condition for control or data acquisition purposes such as:

7.1.4.1 **Combustion Chamber Static Pressure Sensor (P0)**—A sensor installed to measure the static pressure within the combustion chamber before and after each combustion cycle.

7.1.4.2 **Combustion Chamber Dynamic Pressure Sensor (P1)**—A sensor installed to measure the pressure within the combustion chamber during each combustion cycle. The pressure sensor is fitted with an integrated temperature sensor to record the operating temperature (T3) at the sensor.

7.1.4.3 **Injection Actuator Air Pressure Regulator (P2)**—A calibrated pressure regulator installed between the pneumatic air supply and the fuel injection pump actuator.

7.1.4.4 **Combustion Chamber Inner Wall Temperature Sensor (T2)**—A type K thermocouple with stainless steel sheath, inserted in a well fastened to the inner surface of the chamber.

7.1.4.5 **Chamber Charge Air Temperature Sensor (T1)**—A type K thermocouple with stainless steel sheath, inserted in the combustion chamber.

7.1.4.6 **Fuel Injection Pump Temperature Sensor (T4)**—A PT100 temperature sensor with stainless steel sheath, inserted into the fuel injection pump body.

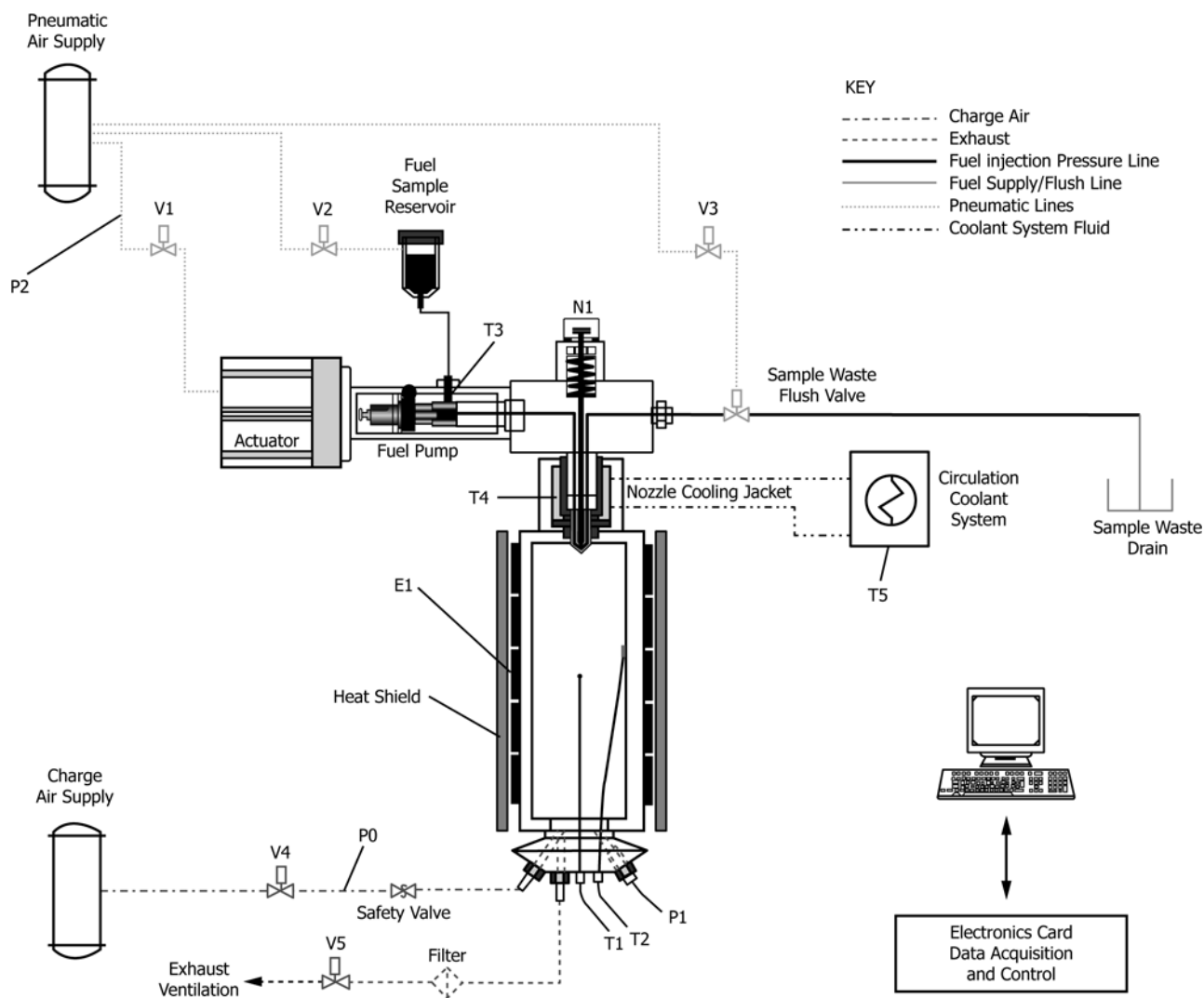
7.1.4.7 **Injector Nozzle Cooling Jacket Temperature Sensor (T5)**—A PT100 temperature sensor with stainless steel sheath, inserted in the injector nozzle coolant passage.

7.1.4.8 **Injector Nozzle Motion Sensor (N1)**—A motion sensor, that can be adjusted to provide a suitable gap between its sensing surface and the end of injector nozzle needle extension pin to detect the start of fuel injection.

7.1.5 **Computerized Control, Data Acquisition, Data Analysis and Reporting System**—A microprocessor controlled system connected to a computer with keyboard for manual entry of operating instructions, a monitor for visual observation of all testing functions, and a printer for printed copy output of test results. The computer-based system provides automated control of the relevant combustion analyzer and sub-system component functions and to collect and process all relevant signals from the injector nozzle needle motion sensor, and temperature and pressure sensors.

⁷ Supporting data, “Sunlight and Air Exposure Effects on Octane Number or Cetane Number of Petroleum Product Samples,” have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1502.

⁸ The sole source of supply of the FIT combustion analyzer known to the committee at this time is Waukesha Dresser, Inc., 1101 West St. Paul Avenue, Waukesha, WI 53188-4999. 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,¹ which you may attend.



V1: Actuator Air Valve
V2: Sample Fuel Reservoir Valve
V3: Sample Waste Flush Valve
V4: Charge Air Valve
V5: Exhaust Valve
E1: Control Power to Chamber Heating
N1: Injection Nozzle Motion Sensor
P2: Injection Actuator Air Pressure Switch Gauge

T1: Chamber Charge Air Temperature
T2: Chamber Inner Wall Temperature
T3: Fuel Injection Pump Temperature
T4: Injection Nozzle Cooling Jacket Temperature
T5: Circulation Coolant System Temperature (External)⁴
P0: Chamber Static Pressure Sensor
P1: Chamber Dynamic Pressure Sensor

⁴ T5 is not located on the instrument. It is the temperature of the auxiliary Circulation Coolant System adjusted to maintain T4.

FIG. 1 Combustion Analyzer Schematic

7.2 Refer to the instruction manual of the manufacturer⁹ for detailed information.

7.3 Compressed Gas Pressure Regulators:

⁹ The instruction manual is available from Waukesha Dresser, Inc., 1101 West St. Paul Avenue, Waukesha, WI 53188-4999.

7.3.1 *Charge Air Regulator*—A two-stage regulator capable of controlling the downstream pressure to a minimum pressure of 2.40 MPa.

7.3.2 *Pneumatic Air Regulator*—A two-stage regulator capable of controlling the downstream pressure to a minimum pressure of 0.75 MPa.

7.4 Auxiliary Apparatus:

7.4.1 *Diesel Fuel Oil Sample Filter*—A single-use glass fiber, polytetrafluoroethylene (PTFE), or nylon filter with a nominal pore size of 3 to 5 micrometers (μm) for use with a glass syringe.

7.4.2 *Syringe*—A glass syringe of a minimum volume of 100 mL.

8. Reagents and Materials

8.1 Calibration Reference Materials:

8.1.1 *Heptane*—With a minimum purity of 99.5 volume percent. The assigned IDARV for this material and this method is 3.15 ms (**Warning**—Flammable. Vapor harmful. Vapor may cause flash fire.)

8.1.2 *Methylcyclohexane*—With a minimum purity of 99.0 volume percent. The assigned IDARV for this material and this method is 10.1 ms (**Warning**—Flammable. Vapor harmful. Vapor may cause flash fire.)

NOTE 2—Experience has found some MCH meeting the purity specification but which does not meet ignition delay ARV (typically 1 to 1.5 milliseconds shorter). It is recommended that new material be qualified prior to use.

8.2 Check Standard:

8.2.1 *Heptane*—With a minimum purity of 99.5 volume percent (see 8.1.1).

8.3 *Quality Control Sample*—A stable and homogeneous diesel fuel oil having physical and chemical properties similar to those of typical sample fuels routinely tested (**Warning**—Combustible. Vapor Harmful.)

8.4 *Charge Air*—A compressed air containing 20.9 ± 1.0 volume percent oxygen (O_2), less than 0.5 PPM CO , less than 1.0 PPM CO_2 , less than 5 PPM H_2O , less than 0.1 PPM NO_x , less than 0.1 PPM SO_2 , and less than 0.1 PPM Total Hydrocarbon Content (THC). (**Warning**—Compressed gas under high pressure that supports combustion.)

NOTE 3—This grade air is typically referred to as Continuous Emissions Monitoring Grade Air (CEM).

8.5 *Coolant System Fluid*—A50:50 volume mixture of water and commercial ethylene glycol-based antifreeze (**Warning**—Poison. May be harmful or fatal if inhaled or swallowed.)

8.5.1 *Antifreeze*—A commercial automotive cooling system ethylene glycol-based solution.

8.5.2 *Water*—A distilled or reagent-grade, conforming to Specification D1193, Type IV.

8.6 *Pneumatic Air*—An oil free compressed air having less than 0.1 volume percent water (**Warning**—Compressed gas under high pressure that supports combustion.)

9. Sampling and Test Specimen Preparation

9.1 Sampling:

9.1.1 Collect diesel fuel oil samples in accordance with Practices D4057 or D4177.

9.1.1.1 **Warning**—Collect and store diesel fuel oil samples in a suitable container such as a dark brown bottle, a metal can, or a minimally reactive plastic container to minimize exposure to UV emissions.

9.1.2 Refer to Practice D5854 for appropriate information relating to the mixing and handling of diesel fuel oil samples.

9.2 Test Specimen Preparation:

9.2.1 *Sample Fuel Temperature*—Condition the diesel fuel oil sample before opening the storage container, so that it is at room temperature, typically 18 to 32°C.

9.2.2 *Filtration*—Samples may be filtered through a Type I, Class A filter paper at room temperature and pressure before testing (see Specification E832), or through a nominal 3 to 5 μm porosity filter element using a syringe.

9.2.2.1 Collect the specimen in a dark brown bottle, metal can or minimally reactive plastic container.

10. Basic Apparatus Settings and Standard Operating Conditions

10.1 Installation of the apparatus requires placement on a level surface and connection of all utilities. Engineering and technical support for this function is required, and the user shall be responsible to comply with all local and national codes and installation requirements.

10.2 Operation of the combustion analyzer, associated equipment, instrumentation, and computer system requires setting a series of testing variables to prescribed specifications. Some of these settings are established by component specifications, others are operating conditions that are monitored or controlled by the computer software or by operator adjustment.

10.3 Settings Based on Component Specifications:

10.3.1 *Injector Nozzle Opening Pressure*—Each time the nozzle assembly is reassembled or replaced, or both, set the pressure-adjusting nut to release fuel in conformance with the requirements of the manufacturer, using a pressure sensor connected to the nozzle housing through an appropriate adapter. For additional details, refer to the instruction manual of the manufacturer.⁹

10.3.2 *Injector Nozzle Motion Sensor Position*—Verify Sensor positioning using the appropriate function of the apparatus software. If required, manually adjust the position of the motion sensor by referring to the instruction manual of the manufacturer,⁹ using the appropriate function of the apparatus software.

10.3.3 *Combustion Chamber Leakage Rate*—Shall be less than 2.0 kPa/s, as measured during the automated check of the sealing integrity of the combustion chamber.

NOTE 4—After the warm-up sequence (see 12.1.1) is finished, the computer system initiates an automatic diagnostic procedure consisting of zero-adjustment of the chamber dynamic pressure sensor (P1) and a chamber sealing integrity check. The chamber leakage rate is continuously monitored by the computer system throughout the test and in between tests.

10.4 Standard Operating Conditions:

10.4.1 *Chamber Static Pressure (P0)*—The average of 25 combustion cycles for Chamber Static Pressure is required to be within 2.40 ± 0.02 MPa.

10.4.2 *Chamber Charge Air Temperature (T1)*, $510 \pm 50^\circ\text{C}$.

10.4.3 *Chamber Inner Wall Temperature (T2)*—Initially set by the manufacturer, the surface temperature set-point is

monitored and controlled by the computer. Operator adjustment of the controller set-point is required, in accordance with the calibration procedure.

10.4.3.1 The difference in temperature ($T_{2\max} - T_{2\min}$) as determined and recorded by the computer, shall be less than 2.5°C during a 25 combustion cycle measurement determination.

10.4.4 To ensure proper heat distribution and guard against malfunctioning of the heater element the temperature difference ($T_2 - T_1$) shall be within the tolerances, as referred to in the instruction manual of the manufacturer⁹ for each of the 25 combustion cycles. The difference ($T_2 - T_1$) is monitored by the computer.

10.4.5 *Fuel Injection Pump Temperature (T_3)*, $35 \pm 2^{\circ}\text{C}$.

10.4.6 *Injector Nozzle Coolant Jacket Temperature (T_4)*—Set the coolant reservoir temperature (T_5) to achieve an injector nozzle coolant passage temperature (T_4) of $30.0 \pm 0.5^{\circ}\text{C}$. T_4 is determined and recorded by the computer. A temperature outside the range given during a 25 combustion cycle measurement indicates a possible malfunctioning of the cooling system.

10.4.7 *Injection Actuator Air Pressure (P_2)*, $0.75 \pm 0.05\text{ MPa}$.

10.4.8 *Injection Period (IP)*:

10.4.8.1 The average injection period over 25 combustion cycles: $5.00 \pm 0.25\text{ ms}$.

10.4.8.2 The individual injection period for each of the 25 combustion cycles: $5.00 \pm 1.00\text{ ms}$.

10.4.8.3 Each individual injection period and the updated average is continuously monitored and recorded by the computer. If necessary, to comply with these requirements, the rack setting on the fuel pump can be adjusted manually.

11. Calibration and Quality Control Testing

11.1 *Calibration*—Calibrate the combustion analyzer (1) after it is installed and commissioned, (2) after replacement of critical parts or components of combustion chamber assembly, fuel injection system or instrument sensors, (3) after calibration of the injection actuator air pressure, chamber static pressure, or chamber dynamic pressure sensors, or (4) whenever check standard or QC sample determinations are not in statistical control, and the assignable causes for QC non-compliance have been suitably addressed.

11.2 *Pre-calibration Procedures*:

11.2.1 Start and warm-up the combustion analyzer (see 12.1.1).

11.3 *Calibration Procedure*—Two calibration reference materials are tested: (1) heptane to affirm that the combustion chamber charge air temperature setting produces ignition delay measurements for this material that are within specification limits and, (2) methylcyclohexane to affirm that the measurement sensitivity of the combustion analyzer produces ignition delay measurements for this material that are within specification limits.

11.3.1 *Heptane Calibration Reference Material*—Perform three consecutive ignition delay determinations.

11.3.1.1 To be an acceptable data set, each single result is required to be within $3.15 \pm 0.04\text{ ms}$.

11.3.1.2 The average of three acceptable ID results is required to be within $3.15 \pm 0.02\text{ ms}$.

11.3.1.3 If any of the three results is outside the limits, a system malfunction is suspected and diagnostic procedures to determine and remedy the problem are recommended before performing a new calibration. Refer to the instruction manual of the manufacturer.⁹

11.3.1.4 If the average ID is outside the limits, the combustion chamber inner surface temperature controller set-point requires adjustment to cause a change in the combustion chamber charge air temperature.

NOTE 5—ID increases when the combustion chamber inner surface temperature decreases and vice versa.

11.3.1.5 If the temperature controller set-point adjustment from the previous setting exceeds $\pm 4^{\circ}\text{C}$, a system malfunction is suspected and diagnostic procedures to determine and remedy the problem are recommended. Refer to the instruction manual of the manufacturer.⁹

NOTE 6—After a change of charge air cylinders, a temperature controller set-point adjustment beyond 4°C can accommodate the extreme limits of the 20.9 ± 1.0 volume percent oxygen.

11.3.1.6 After a temperature controller set-point adjustment, wait at least 10 min before initiating a new calibration so that the combustion analyzer attains thermal equilibrium. Adequate temperature stability is determined and automatically controlled by the computer.

11.3.2 *Methylcyclohexane Calibration Reference Material*—Perform two consecutive ignition delay determinations.

11.3.2.1 To be an acceptable data set, each single result is required to be within $10.1 \pm 0.6\text{ ms}$ and the average of the two results is required to be within $10.1 \pm 0.5\text{ ms}$.

11.3.2.2 If either of the two single results or the average of the two results is outside the respective limits, system performance is unacceptable and it is recommended that diagnostic procedures be used to determine and remedy the problem before performing a new calibration. Refer to the instruction manual of the manufacturer.⁹

11.3.3 The combustion analyzer calibration is complete when both heptane and methylcyclohexane data sets are acceptable.

11.4 *Quality Control (QC Testing)*—Conduct a regular statistical quality assurance (quality control) program in accordance with the techniques of Practice D6299 or equivalent.

11.4.1 This test method requires quality control testing at the beginning of each operating period by a single ignition delay determination for both the check standard (heptane) and one QC sample.

11.4.2 The QC sample is a typical diesel fuel oil having an ignition delay that represents the primary range of use for the combustion analyzer.

11.4.2.1 If the combustion analyzer is used for testing fuels having a very wide range of ignition delay, it may be useful to have a second QC sample of a different ignition delay.

11.4.3 For locations using blends of oxygen and nitrogen as the source for charge air, conduct a QC test whenever there is a change from one cylinder to another.

NOTE 7—The oxygen content of the new oxygen and nitrogen blend may differ from that of the previous source and can have a significant effect on ID measurements.

11.5 *Check Standard*—Perform a single ignition delay determination for heptane.

11.5.1 This determination is acceptable if it satisfies the limits protocol specified in Practice D6299 or equivalent.

11.5.2 Prior to having established ignition delay tolerances for heptane in accordance with Practice D6299 or equivalent, use warning limits of ± 0.04 ms and action limits of ± 0.06 ms, based on the average of the three acceptable ID results for heptane, as per 11.3.1.

11.6 *QC Sample*—Perform a single ignition delay determination for the QC sample.

11.6.1 This determination is acceptable if it satisfies the limits protocol specified in Practice D6299 or equivalent.

11.7 The combustion analyzer is fit-for-use when both the check standard (heptane) and the QC sample ignition delay determinations are acceptable. If the ignition delay determination for either material is not acceptable, conduct a new calibration before performing further ignition delay determinations.

12. Procedure

12.1 Operating Period Procedure:

12.1.1 With the combustion analyzer in shut down mode, start a new operating period as follows:

12.1.1.1 Position the combustion analyzer power switch to ON.

12.1.1.2 Open the valve at the source of the charge air supply and adjust the pressure regulators as needed to provide the specification pressures. Turn on the computer, circulation coolant system, and the pneumatic air supply.

12.1.1.3 Initiate the automated warm-up sequence using the appropriate computer command.

12.1.2 Check that the combustion analyzer is fit-for use by performing a quality control test (see 11.4).

12.2 Test Procedure:

12.2.1 Prepare a test specimen of at least 220 mL.

12.2.2 Remove the reservoir cap and fill the fuel reservoir with the test specimen. Reinstall the reservoir cap hand tight.

12.2.2.1 Flush all the test specimen through the fuel injection system by pressing the appropriate button and keep it pressed until the fuel reservoir is empty. Refer to the instruction manual of the manufacturer.⁹

12.2.2.2 Remove the reservoir cap and refill the fuel reservoir with the test specimen. Reinstall the reservoir cap hand tight and initiate the flushing sequence by pushing for 3 s the appropriate button on the apparatus.

12.2.2.3 Remove the reservoir cap and top off the fuel reservoir with the test specimen. Reinstall the reservoir cap hand tight.

12.2.3 Initiate an automatic ignition delay determination using the appropriate computer command (see Annex A2 for detailed information about the test sequence).

12.2.4 After the two pre-injections, monitor the injection period throughout the test to ensure that the injection period average is 5.00 ± 0.25 ms and the injection periods all fall

between 4.0 and 6.0 ms. If adjustments of the fuel injection pump rack are required to achieve these conditions, make the necessary adjustments and, using the same fuel test specimen contained in the fuel reservoir from the previously aborted test, start a new test by repeating steps 12.2.2.3, 12.2.3, and 12.2.4. To make these adjustments, refer to Fig. 2 and the instruction manual of the manufacturer.⁹

NOTE 8—The Test Output “Results Status” line will state “Test completed with errors” if the injection period is outside the specified limits.

NOTE 9—Moving the rack towards the rear of the cabinet increases the injection period duration, and moving the rack towards the front of the cabinet reduces the injection period.

12.2.5 At the end of the test, a test output summary is automatically stored on the computer hard drive and displayed on the computer screen. The user can optionally print the results with a connected printer. The report contains detailed information about each of the 25 combustion cycles including ID, DCN, IP (injection period), and some of the important operating conditions. At the bottom of the printout, the average value, minimum, maximum, range, and standard deviation of critical measurements are given (see Appendix X1).

12.2.5.1 The ID result at the bottom of the printout is obtained by averaging the ID measurements of the last 25 cycles.

12.2.5.2 The DCN result at the bottom of the printout is obtained by converting the mean ID result to DCN using:

$$\text{DCN} = 150.4 \cdot (1/\text{ID}) + 5.3 \quad (1)$$

12.2.6 Check that all standard operating conditions are in compliance. This test will also be performed by the computer software during and at the end of the test.

12.2.7 Flush the remaining test specimen through the fuel injection system by pressing the appropriate button and keep it pressed until the fuel reservoir is empty.

12.2.8 Remove the reservoir cap and visually inspect that the fuel reservoir is empty. Reinstall the fuel reservoir cap hand tight. The fuel system is now prepared for the next specimen determination (see 12.2) or unit shutdown (see 12.3).

12.3 Unit Shutdown:

12.3.1 Confirm that all specimens have been discharged from the fuel injection system (see 12.2.7) and that the fuel reservoir is empty (see 12.2.8).

12.3.2 Close the valve at the source of the charge air supply. Use the applicable computer command to shutdown the combustion analyzer. Turn off the computer, circulation coolant system, and the pneumatic air supply.

NOTE 10—The shutdown procedure decompresses the combustion chamber and switches off the heating element to allow the combustion chamber to cool down.

12.3.3 Position the combustion analyzer power switch to OFF.

13. Calculation

13.1 Calculate the derived cetane number, DCN, from average ignition delay, ID (ms), recorded as in 12.2.5.2 using Eq 1.

$$\text{DCN} = 150.4 \cdot (1/\text{ID}) + 5.3$$

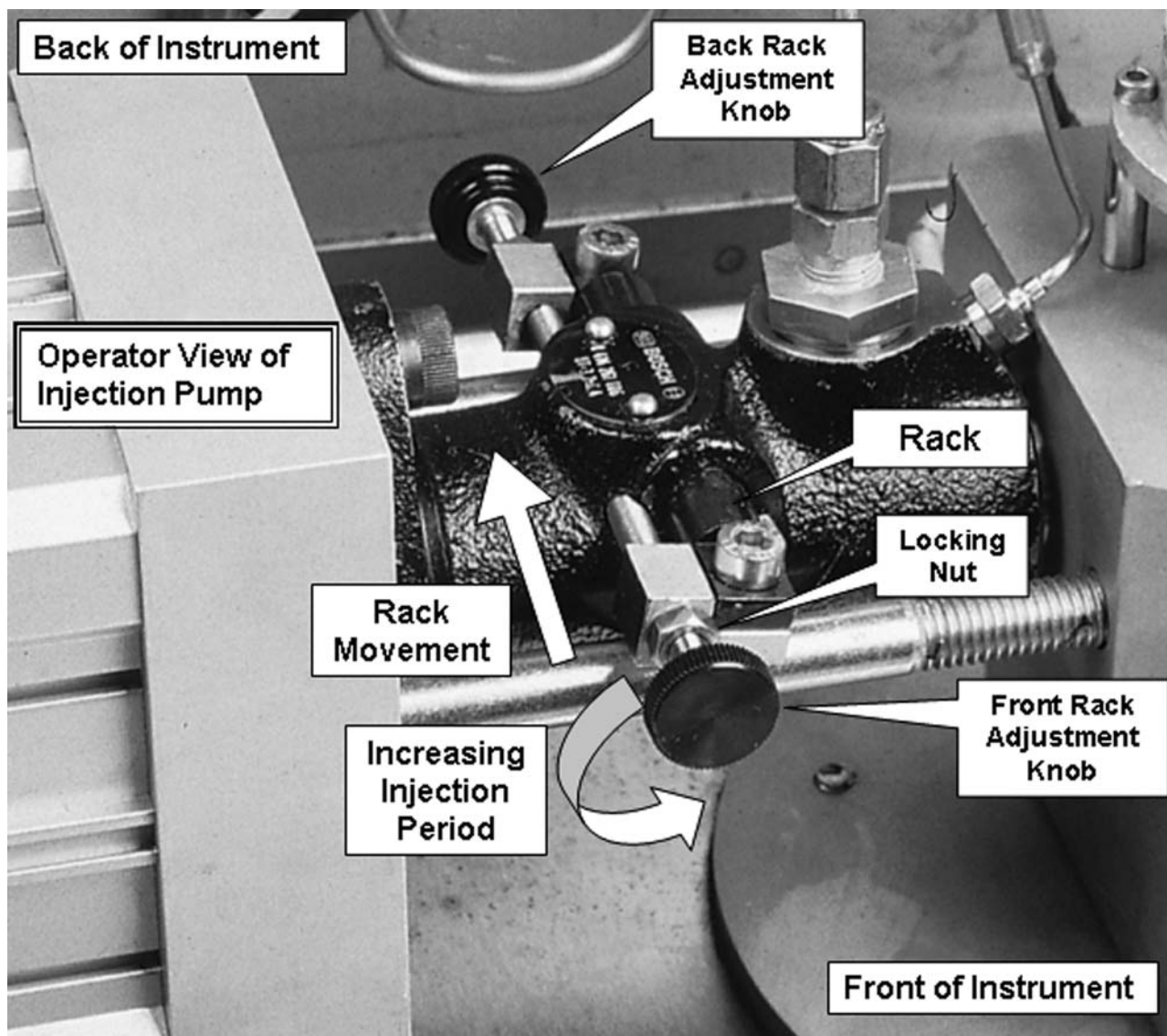


FIG. 2 Fuel Injection Pump Rack Adjustment

13.2 Record the DCN to the nearest 0.1.

13.3 The derivation and maintenance of Eq 1 is described in Annex A3.

14. Report

14.1 Report the following information:

14.1.1 A reference to this standard,

14.1.2 The sample identification,

14.1.3 The date of the test,

14.1.4 The ID result to the nearest hundredth (0.01 ms),

14.1.5 The DCN result to the nearest tenth (0.1),

14.1.6 The test's average charge air temperature to the nearest tenth °C,

14.1.7 Any deviation, by agreement or otherwise, from the specified procedures,

14.1.8 Whether or not the sample was filtered, and

14.1.9 If the sample was filtered, report the media that was used for filtration.

15. Precision and Bias

15.1 *Precision*—The precision statements for ID and DCN are based on results from the Interlaboratory Study (ILS) conducted from May to July of 2007.¹⁰ The study involved 15 samples (12 instruments; 12 operators), and covered DCN results ranging from a minimum value of 35.0 DCN (ignition delay of 4.89 ms) to a maximum value of 59.6 (ignition delay of 2.87 ms). The average DCN result for each sample ranged from 37.29 DCN (average ignition delay of 4.5894 ms) to 56.517 (average ignition delay of 3.0281 ms).

NOTE 11—The precision listed in this test method was obtained on unfiltered samples. Refer to ASTM Research Report RR:D02-1641.¹⁰

NOTE 12—A robust statistical study was performed on filtered and unfiltered samples with respect to DCN measurement. The conclusion of the study was, “No statistically observable effect between filtered vs.

¹⁰ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting ASTM Research Report RR:D02-1641.

TABLE 1 Repeatability (r) and Reproducibility (R) for Ignition Delay (ID) and Derived Cetane Number (DCN)

	ID (ms)	DCN
Repeatability (r)	0.023 · ID	0.072 · DCN ^{0.7}
Reproducibility (R)	0.082 · ID	0.262 · DCN ^{0.7}

TABLE 2 Repeatability and Reproducibility Values for Information

ID (ms)	Repeatability	Reproducibility
3.15	0.072	0.258
3.40	0.078	0.279
3.65	0.084	0.299
3.90	0.090	0.320
4.15	0.095	0.340
4.40	0.101	0.361
DCN	Repeatability	Reproducibility
55.2	1.19	4.34
51.2	1.13	4.12
47.7	1.08	3.92
44.6	1.03	3.74
41.9	0.98	3.58
39.5	0.94	3.44

TABLE 3 Between Method Reproducibility (R_{XY})

= (DCN + CN _{D613})/2	Reproducibility
40	3.45
44	3.84
48	4.24
52	4.64
56	5.04
$R_{XY} = [(0.6 \text{ DCN}^2) + (0.6 \text{ CN}_{D613}^2)]^{0.5}$	

non-filtered results.” Refer to ASTM Research Report RR:D02-1658.¹¹

15.1.1 Repeatability—The difference between successive results obtained by the same operator with the same apparatus, under constant operating conditions, on identical test materials

¹¹ Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1658.

would, in the long run, in the normal and correct operation of the test method, exceed the values in **Table 1** only in one case in twenty.

NOTE 13—The Fuel Ignition Tester (FIT) was used to develop this precision statement.⁸

15.1.2 Reproducibility—The difference between two single independent results obtained on identical test samples under reproducibility conditions would, in the long run, in the normal and correct operation of the test method, exceed the values in **Table 1** only one case in twenty.

NOTE 14—The degrees of freedom associated with the reproducibility estimate from this round robin study are 20. Since the minimum requirement of 30 (in accordance with Practice **D6300**) is not met, users are cautioned that the actual reproducibility estimate may be significantly different than this estimate.

15.1.3 Examples of precision are shown in **Table 2** for information.

15.2 Initial Tentative Precision (2004)—Initial tentative precision was based on results from a within-laboratory study conducted in April 2004. The study involved 22 samples (2 instruments; 1 operator) comprising some samples from the 2003 and 2004 NEG diesel exchange and NEG Cetane Check Fuel and covered DCN range from 40.8 to 58.6 DCN (Ignition Delay range 4.26 to 2.97 ms).

15.3 Bias—The ID determined using this test method has no bias because ID is defined only in terms of this test method.

15.4 No bias-correction considered in Practice **D6708** can further improve the agreement between results from Test Method D7170 and Test Method **D613**.

15.4.1 Between Method Reproducibility—Differences between results from Test Method D7170 and Test Method **D613**, for the sample types and property ranges studied, are expected to exceed the values in **Table 3** Between Method Reproducibility (R_{XY}), as defined in Practice **D6708**, about 5 % of the time.

16. Keywords

16.1 cetane number; derived cetane number; diesel performance; ignition characteristic; ignition delay

ANNEXES

(Mandatory Information)

A1. HAZARDS INFORMATION

INTRODUCTION

In the performance of the standard test method there are hazards to personnel. These are indicated in the text. For more detailed information regarding the hazards, refer to the appropriate Material Safety Data Sheet (MSDS) for each of the applicable substances to establish risks, proper handling, and safety precautions.

A1.1 Warning—Combustible. Vapor Harmful.

A1.1.1 Applicable Substances:

A1.1.1.1 Diesel fuel oil, and

A1.1.1.2 Quality control sample.

A1.2 Warning—Flammable. Vapors Harmful if Inhaled. Vapors May Cause Flash Fire.

A1.2.1 Applicable Substances:

A1.2.1.1 Heptane, and

A1.2.1.2 Methylcyclohexane.

A1.3 Warning—Poison. May be Harmful or Fatal if Inhaled or Swallowed.

A1.3.1 Applicable Substance:

A1.3.1.1 Ethylene glycol based antifreeze.

A1.4 Warning—Compressed gas under high pressure that supports combustion.

A1.4.1 Applicable Substance:

A1.4.1.1 Compressed air.

A1.5 Warning—Hot surfaces.

A1.5.1 Applicable Surfaces:

A1.5.1.1 Protective cage enclosing the combustion chamber,

A1.5.1.2 Exposed areas of the combustion chamber around the injector nozzle,

A1.5.1.3 Exposed areas of the combustion chamber,

A1.5.1.4 Near the combustion chamber, and

A1.5.1.5 Inside the combustion chamber protective cage.

A2. SUPPLEMENTAL PROCEDURE INFORMATION

A2.1 Test Sequence

A2.1.1 General—An automated test run consists of 2 preliminary (pre-test injections) + 25 subsequent (test injections) combustion cycles. A combustion cycle involves: (1) charging the chamber to the test pressure, (2) injecting a small volume of fuel sample into the combustion chamber, and (3) releasing of the combustion gases. During the combustion cycle, the injector nozzle needle motion sensor measures the motion of the injector nozzle needle and the chamber dynamic pressure sensor measures the pressure within the chamber.

A2.1.2 A simplified example of the output of the nozzle needle motion sensor and the chamber dynamic pressure sensor recorded for a single combustion cycle during a test sequence is shown in [Fig. A2.1](#).

A2.1.3 The ignition delays of the 25 combustion cycles are averaged to produce the analytical ID result.

A2.1.4 During each of the 25 combustion cycles the following parameters are recorded:

Parameters
Ignition Delay (ID)
Chamber Static Pressure (P0)
Chamber Dynamic Pressure Maximum (P1 _{max})
Chamber Charge Air Temperature (T1)
Chamber Inner Wall Temperature (T2)
Fuel Injection Pump Temperature (T3)
Injection Nozzle Coolant Jacket Temperature (T4)
Injection Period (IP)

A2.1.5 The individual measured values of the above parameter for each of the 25 combustion cycles as well as their average, minimum and maximum are automatically stored in a test report during each test (see [Appendix X1](#)).

A2.1.6 Upon successful completion of the test the following equation is applied to convert Mean ID to DCN:

$$DCN = 150.4 \cdot (1/ID) + 5.3 \quad (A2.1)$$

where:

ID = average ignition delay in milliseconds calculated on the basis of 25 recordings, and

DCN = derived cetane number.

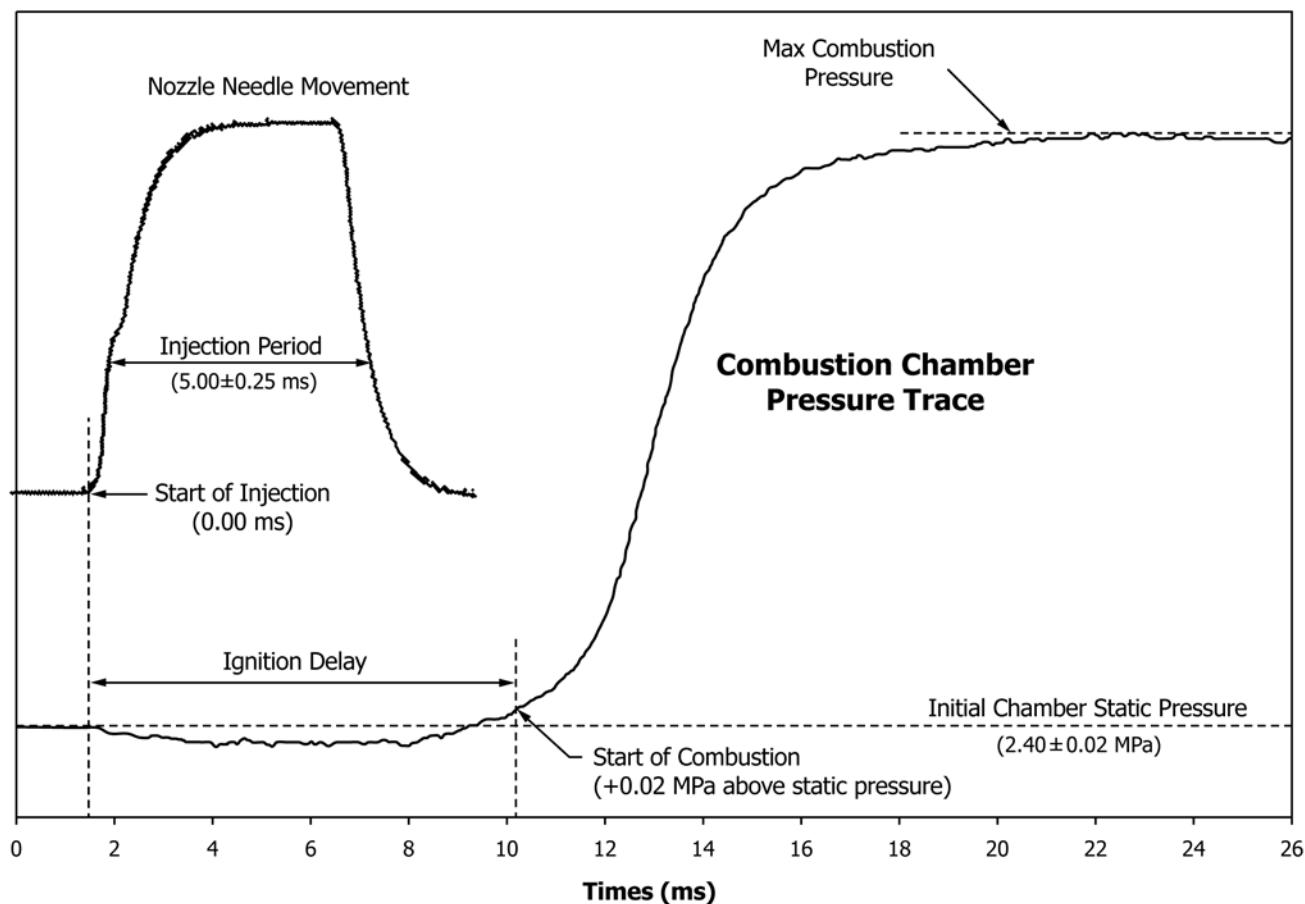


FIG. A2.1 Signals of Motion Sensor and Chamber Dynamic Pressure Sensor During a Single Combustion Cycle

A3. DERIVATION AND MAINTENANCE OF DCN EQUATION

A3.1 Derived cetane number (DCN) is defined as a number calculated using a conversion equation to determine a cetane number (see 3.2.5).

A3.2 This equation has been derived using the 2007 ILS data set. The derivation is described in ASTM Research Report RR:D02-1641.¹⁰

A3.3 The correlation equation (Eq 1) appears in Section 13. The ongoing validation of the DCN equation shall be moni-

tored and evaluated through the monthly NEG and EI fuel exchange programs. The validation data shall be reviewed by Subcommittee D02.01 through the application of Practice D6708 with a frequency of at least every three years. As a result of the review, Subcommittee D02.01 may make the decision to, if necessary, modify the existing equation or develop a new one. As part of this review, the sample types will be examined, and if certain types are underrepresented, further steps may be taken to evaluate how they perform.

APPENDIX

(Nonmandatory Information)

X1. EXAMPLE OF TEST OUTPUT

Date:

05-17-2004

Time:

15:30:35

Instr ID:

001.05.0203

Fuel ID:

xxxx

Temp. ref:

572.7

Test comment:

d960

	ID	P0	P1 (MAX)	T1	T2	T4	T3	IP
	Ign.	Charge	Max	Air	Wall	Water	Fuel	Inj.
Inj no.	Delay	press	press	temp	temp	temp	temp	Period
1	4.13	24.06	7.24	536.8	572.2	29.9	35.0	5.00
2	3.85	24.00	7.42	535.6	571.8	29.9	34.8	5.05
3	4.02	24.01	7.34	535.6	571.8	29.9	34.8	5.05
4	3.82	23.98	7.39	536.2	571.8	29.9	35.0	5.05
5	3.62	24.01	7.39	536.2	571.8	29.9	35.2	5.00
6	4.09	23.93	7.30	535.4	571.6	29.9	35.0	5.00
7	4.00	23.95	7.25	535.6	571.4	29.9	34.8	5.05
8	4.17	23.96	7.21	536.4	571.4	29.9	34.8	5.00
9	4.02	24.06	7.34	535.6	571.4	29.9	35.0	5.05
10	3.90	23.97	7.66	535.6	571.6	29.9	35.2	5.15
11	4.08	24.01	7.61	537.0	571.8	29.9	35.0	5.10
12	4.33	23.95	7.61	537.0	571.8	29.9	34.8	5.15
13	3.93	24.01	7.87	536.6	572.0	29.9	34.8	5.20
14	3.88	24.01	7.80	536.4	572.0	29.9	35.0	5.15
15	3.90	24.01	7.98	536.6	572.2	29.9	35.2	5.20
16	3.67	23.95	7.84	537.4	572.2	29.9	35.0	5.20
17	3.87	24.10	7.84	536.4	572.4	29.9	35.0	5.15
18	3.74	23.96	7.91	537.7	572.6	29.9	35.2	5.20
19	3.96	23.98	7.99	538.3	572.9	29.9	35.0	5.20
20	4.08	23.95	8.15	537.4	573.3	29.9	35.0	5.25
21	3.87	24.00	8.14	538.3	573.1	29.9	35.0	5.25
22	3.94	24.00	8.13	537.4	573.3	29.9	35.2	5.25
23	3.86	24.01	7.89	538.3	573.3	29.9	35.0	5.25
24	3.76	23.95	8.14	538.3	573.3	29.9	35.0	5.25
25	3.80	24.00	8.01	538.1	573.1	29.9	35.2	5.25
Mean	3.93	23.99	7.70	536.8	572.2	29.9	35.0	5.14
Std Dev	0.16	0.04	0.33	1.0	0.7	0.0	0.1	0.09
Min	3.62	23.93	7.21	535.4	571.4	29.9	34.8	5.00
Max	4.33	24.10	8.15	538.3	573.3	29.9	35.2	5.25
Range	0.71	0.17	0.94	2.9	1.9	0.0	0.4	0.25

Charge Press:

Min/Max Ok (>23.0/<25.0). Avg Ok (>23.8/<24.2).

Max Press:

Range Ok (<2.0).

Air Temp:

Range Ok (<5.0).

Wall Temp:

Min/Max Ok (>570.7/<574.7). Avg Ok (>572.0/<573.4).

Water Temp:

Min/Max Ok (>29.2/<30.8). Avg Ok (>29.5/<30.5).

Fuel Temp:

Min/Max Ok (>32.0/<38.0). Avg Ok (>33.0/<37.0).

Inj Period:

Min/Max Ok (>4.0/<6.0). Avg Ok (>4.75/<5.25).

Result Status:

Test finished successfully.

DCN:

44.3

FIG. X1.1 Example of Test Output

SUMMARY OF CHANGES

Subcommittee D02.01 has identified the location of selected changes to this standard since the last issue (D7170 – 12a) that may impact the use of this standard. (Approved May 1, 2014.)

(1) Revised Eq 1, Eq 1, and Eq A2.1.

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