Designation: ~~D613 – 18a^ε1^~~ D613 – 23

Standard Test Method for Cetane Number of Diesel Fuel Oil[1]

This standard is issued under the fixed designation D613; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

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

~~ε1 NOTE—IP logo removed in January 2021 as methods are not considered technically equivalent.~~

1. Scope*

1.1 This test method covers the determination of the rating of diesel fuel oil in terms of an arbitrary scale of cetane numbers using a standard single cylinder, four-stroke cycle, variable compression ratio, indirect injected diesel engine.

1.2 The cetane number scale covers the range from zero (0) to 100, but typical testing is in the range of 30 to 65 cetane number.

1.3 The values for operating conditions are stated in SI units and are to be regarded as the standard. The values given in parentheses are the historical inch-pound units for information only. In addition, the engine measurements continue to be in inch-pound units because of the extensive and expensive tooling that has been created for these units.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* For more specific warning statements, see Annex A1.

1.5 *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.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D975 Specification for Diesel Fuel
D1193 Specification for Reagent Water
D2500 Test Method for Cloud Point of Petroleum Products and Liquid Fuels
D3703 Test Method for Hydroperoxide Number of Aviation Turbine Fuels, Gasoline and Diesel Fuels
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
D6299 Practice for Applying Statistical Quality Assurance and Control Charting Techniques to Evaluate Analytical Measurement System Performance

[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] 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.

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

D6300 Practice for Determination of Precision and Bias Data for Use in Test Methods for Petroleum Products, Liquid Fuels, 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
E542 Practice for Gravimetric Calibration of Laboratory Volumetric Instruments
E832 Specification for Laboratory Filter Papers

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 which is derived as: (*1*) a theoretical or established value, based on scientific principles, or (*2*) an assigned or certified value, based on experimental work of some national or international organization, or (*3*) a consensus or certified value, based on collaborative experimental work under the auspices of a scientific or engineering group. **E456**

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

3.1.2 *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**

3.1.2.1 *Discussion—*
In the context of this test method, ignition performance is understood to mean the ignition delay of the fuel as determined in a standard test engine under controlled conditions of fuel flow rate, injection timing, and compression ratio.

3.1.3 *compression ratio (CR), n*—the ratio of the volume of the combustion chamber including the precombustion chamber with the piston at bottom dead center to the comparable volume with the piston at top dead center.

3.1.4 *ignition delay, n*—that period of time, expressed in degrees of crank angle rotation, between the start of fuel injection and the start of combustion.

3.1.5 *injection timing (injection advance), n*—that time in the combustion cycle, measured in degrees of crank angle, at which fuel injection into the combustion chamber is initiated.

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**

3.1.7 *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**

~~3.1.7.1 *Discussion—*~~
~~In the context of this test method, a short time interval between two ratings on a sample fuel is understood to be not less than the time to obtain at least one rating on another sample fuel between them but not so long as to permit any significant change in the sample fuel, test equipment, or environment.~~

3.1.8 *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**

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *cetane meter, n*—the electronic apparatus which displays injection advance and ignition delay derived from input pulses of multiple transducers (pickups).

3.2.1.1 *Discussion—*
In the context of this test method, three generations of apparatus have been approved for use as cetane meters. These are (year of introduction is parenthesis) the Mark II Ignition Delay Meter (1974), the Dual Digital Cetane Meter (1990), and the XCP Cetane Panel (2014).

3.2.2 *check fuels, n—*for quality control testing, a diesel fuel oil of selected characteristics having a cetane number accepted reference value determined in accordance with Practice D6299 requirements for check standards derived from interlaboratory exchange programs.

3.2.2.1 *Discussion—*
When evaluating the interlaboratory data to establish the ARV, outlier identification and rejection criteria shall be applied at the 5 % significance level prior to computing the average result.

3.2.3 *combustion pickup, n—*pressure transducer exposed to cylinder pressure to indicate the start of combustion.

3.2.4 *handwheel reading, n—*an arbitrary numerical value, related to compression ratio, obtained from a micrometer scale that indicates the position of the variable compression plug in the precombustion chamber of the engine.

3.2.5 *injector opening pressure, n—*the fuel pressure that overcomes the resistance of the spring which normally holds the nozzle pintle closed, and thus forces the pintle to lift and release an injection spray from the nozzle.

3.2.6 *injector pickup, n—*transducer to detect motion of the injector pintle, thereby indicating the beginning of injection.

3.2.7 *primary reference fuels (PRF), n—*hexadecane (HXD), heptamethylnonane (HMN), pentamethylheptane (PMH), and volumetrically proportioned binary mixtures of HXD with either HMN or PMH, which now define the cetane number scale.

3.2.7.1 *Discussion—*
In the context of this test method, the arbitrary cetane number scale was originally defined as the volume percent of hexadecane in a blend with 1-methylnaphthalene (AMN) where HXD had an assigned value of 100 and AMN an assigned value of zero (0). A change from 1-methylnaphthalene to heptamethylnonane as the low cetane ingredient was made in 1962 to utilize a material of better storage stability and availability. Heptamethylnonane was determined to have a cetane number accepted reference value (CN_{ARV}) of 15 based on engine testing by the ASTM Diesel National Exchange Group.[3] A change to add a second low cetane ingredient, pentamethylheptane (PMH), as an alternative to HMN was made in 2018 to utilize a material of higher purity and better availability. Pentamethylheptane was determined to have a cetane number accepted reference value (CN_{ARV}) of 16.3 based on engine testing by the ASTM Diesel National Exchange Group.[4]

3.2.7.2 *Discussion—*
In the context of this test method, the Diesel National Exchange Group of Subcommittee D02.01[5] is composed of petroleum industry, governmental, and independent laboratories. It conducts regular monthly exchange sample analyses to generate precision data for this engine test standard and determines the CN_{ARV} of reference materials used by all laboratories.

3.2.8 *reference pickups, n—*transducers or optical sensors mounted over the flywheel of the engine, triggered by a flywheel indicator, used to establish a top-dead-center (tdc) reference and a time base for calibration of the cetane meter.

3.2.9 *repeatability conditions NEG, n—*replicate testing conditions employed by the National Exchange Group in which a single operator tests two specimens taken from a single sample container with at least one other sample being tested between the two specimens.

3.2.10 *secondary reference fuels (SRF), n—*volumetrically proportioned blends of two selected, numbered, and paired hydrocarbon mixtures designated *T Fuel* (high cetane) and *U Fuel* (low cetane) that have been rated by the ASTM Diesel National Exchange Group using primary reference fuels to determine a cetane number accepted reference value for each individually and for various combinations of the two.

3.3 *Abbreviations:*

[3] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1092. Contact ASTM Customer Service at service@astm.org.

[4] Supporting data have been filed at ASTM International Headquarters and may be obtained by requesting Research Report RR:D02-1885. Contact ASTM Customer Service at service@astm.org.

[5] Bylaws governing ASTM Subcommittee D02.01 on Combustion Characteristics are available from the subcommittee or from ASTM International.

3.3.1 *ABDC*—after bottom dead center

3.3.2 *AMN*—1-methylnaphthalene

3.3.3 *ARV*—accepted reference value

3.3.4 *ATDC*—after top dead center

3.3.5 *BBDC*—before bottom dead center

3.3.6 *BTDC*—before top dead center

3.3.7 *CN*—cetane number

3.3.8 *CR*—compression ratio

3.3.9 *DD*—Dual Digital Cetane Meter

3.3.10 *HMN*—heptamethylnonane

3.3.11 *HRF*—high reference fuel

3.3.12 *HW*—hand wheel

3.3.13 *HXD*—hexadecane

3.3.14 *IAT*—intake air temperature

3.3.15 *LRF*—low reference fuel

3.3.16 *NEG*—National Exchange Group

3.3.17 *PMH*—pentamethylheptane

3.3.18 *PRF*—primary reference fuels

3.3.19 r_{NEG}—repeatablility conditions NEG

3.3.20 *SRF*—secondary reference fuels

3.3.21 *TDC*—top dead center

3.3.22 *UV*—ultraviolet

3.3.23 *XCP*—XCP Cetane Panel

4. Summary of Test Method

4.1 The cetane number of a diesel fuel oil is determined by comparing its combustion characteristics in a test engine with those for blends of reference fuels of known cetane number under standard operating conditions. This is accomplished using the bracketing handwheel procedure which varies the compression ratio (handwheel reading) for the sample and each of two bracketing reference fuels to obtain a specific ignition delay permitting interpolation of cetane number in terms of handwheel reading.

5. Significance and Use

5.1 The cetane number provides a measure of the ignition characteristics of diesel fuel oil in compression ignition engines.

5.2 This test method is used by engine manufacturers, petroleum refiners and marketers, and in commerce as a primary specification measurement related to matching of fuels and engines.

5.3 Cetane number is determined at constant speed in a precombustion chamber type compression ignition test engine. The relationship of test engine performance to full scale, variable speed, variable load engines is not completely understood.

5.4 This test method may be used for unconventional fuels such as synthetics, vegetable oils, and the like. However, the relationship to the performance of such materials in full scale engines is not completely understood.

6. Interferences

6.1 (**Warning—**Avoid exposure of sample fuels and reference fuels to sunlight or fluorescent lamp UV emissions to minimize induced chemical reactions that can affect cetane number ratings.)[6]

6.1.1 Exposure of these fuels to UV wavelengths shorter than 550 nm for a short period of time may significantly affect cetane number ratings.

6.2 Certain gases and fumes present in the area where the cetane test engine is located may have a measurable effect on the cetane number test result.

6.3 This test method is not suitable for rating diesel fuel oils with fluid properties that interfere with unimpeded gravity flow of fuel to the fuel pump or delivery through the injector nozzle.

7. Apparatus

7.1 *Engine Equipment*[7,8]—This test method uses a single cylinder engine which consists of a standard crankcase with fuel pump assembly, a cylinder with separate head assembly of the precombustion type, thermal syphon recirculating jacket coolant system, multiple fuel tank system with selector valving, injector assembly with specific injector nozzle, electrical controls, and a suitable exhaust pipe. The engine is belt connected to a special electric power-absorption motor which acts as a motor driver to start the engine and as a means to absorb power at constant speed when combustion is occurring (engine firing). See Fig. 1 and Table 1.

7.2 *Instrumentation*[7,8]—This test method uses electronic apparatus to measure injection and ignition delay timing as well as conventional thermometry, ~~gages~~gauges, and general purpose meters.

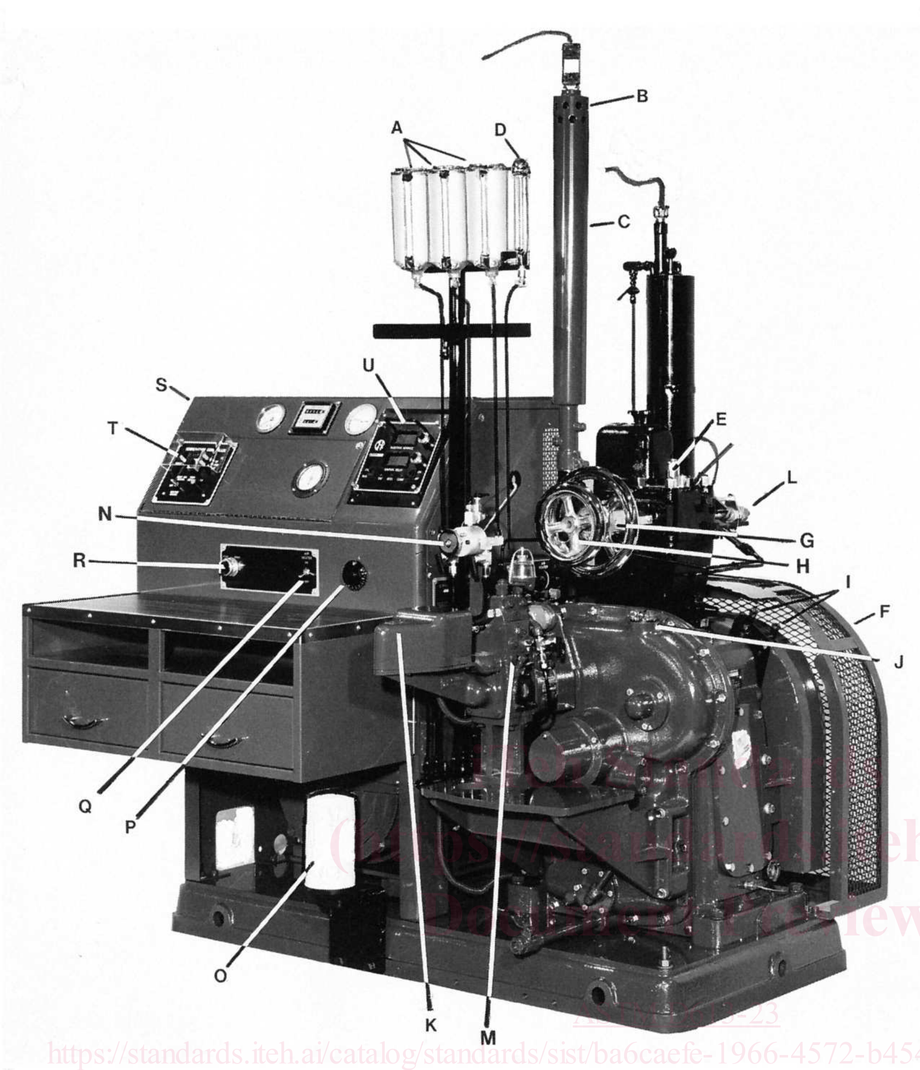
7.2.1 *Cetane Meter*—Use of an approved cetane meter is mandatory; only the XCP Cetane Panel or the Dual Digital Cetane Meter or the Mark II Ignition Delay Meter shall be used for this test method.

7.3 *Reference Fuel Dispensing Equipment*—This test method requires repeated blending of two reference fuel materials in volumetric proportions on an as-needed basis. Measurement shall be performed accurately because rating error is proportional to blending error.

[6] 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.

[7] The sole source of supply of the engine equipment and instrumentation known to the committee at this time is CFR Engines, Inc., N8 W22577 Johnson Dr., Pewaukee, WI 53186. CFR Engines, Inc. also has authorized sales and service organizations in selected geographical areas.

[8] 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.



A—Fuel Tanks
B—Air Heater Housing
C—Air Intake Silencer
D—Fuel Flow Rate Buret
E—Combustion Pickup
F—Safety Guard
G—Variable Compression Plug Handwheel
H—V.C.P. Locking Handwheel
I—Flywheel Pickups
J—Oil Filler Cap
K—Injection Pump Safety Shut-Off Solenoid
L—Injector Assembly
M—Fuel Injection Pump
N—Fuel Selector-Valve
O—Oil Filter
P—Crankcase Oil Heater Control
Q—Air Heater Switch
R—Engine Start-Stop Switch
S—Instrument Panel
T—Intake Air Temperature Controller
U—Dual Digital Cetane Meter

FIG. 1 Cetane Method Test Engine Assembly

7.3.1 *Volumetric Blending of Reference Fuels*—Volumetric blending has historically been employed to prepare the required blends of reference fuels. For volumetric blending, a set of two burets or accurate volumetric ware shall be used and the desired batch quantity shall be collected in an appropriate container and thoroughly mixed before being introduced to the engine fuel system.

7.3.1.1 Calibrated burets or volumetric ware having a capacity of 400 mL or 500 mL and a maximum volumetric tolerance of ±0.2 % shall be used. Calibration shall be verified in accordance with Practice E542.

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

7.3.1.3 The rate of delivery from the dispensing system shall not exceed 500 mL per 60 s.

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

7.3.1.5 See Appendix X1, Volumetric Reference Fuel Blending Apparatus and Procedures, for typical dispensing system information.

7.3.2 *Gravimetric Blending of Reference Fuels*—Use of blending systems that allow preparation of the ~~volumetrically-defined~~

TABLE 1 General Engine Characteristics and Information

Item	Description
Crankcase	Model CFR-48 (Preferred), High or Low Speed Models (Optional)
Cylinder Type	Single bore cast iron with integral coolant jacket
Cylinder Head Type	Cast Iron with turbulence precombustion chamber, variable compression plug passage, integral coolant passages, and in-head valve assembly
Compression Ratio	Adjustable 8:1 to 36:1 by external handwheel assembly
Cylinder Bore (Diameter), in.	3.250 (Standard), Reboring to 0.010, 0.020, 0.030 over is acceptable
Stroke, in.	4.50
Displacement, cu in.	37.33
Valve Mechanism	In-head with enclosure
Intake and Exhaust Valves	Stellite faced, plain type without shroud
Piston	Cast iron, flat top
Piston Rings:	
Compression Type	4, Ferrous, straight sided (Top may be chrome plated—Optional)
Oil Control	1, Cast iron, one piece, slotted (Type 85)
Camshaft Over lap, degree	5
Fuel System	Injection pump with variable timing device and injector
Injector	Holder with bypass pressure release valve
Spray Nozzle	Closed, differential-needle, hydraulically-operated, pintle type
Weight of Engine	Approximately 400 kg (880 lb)
Weight of Complete Test Unit	Approximately 1250 kg (2750 lb)

volumetrically defined blends by gravimetric (mass) measurements based on the density of the individual components is also permitted, provided the system meets the requirement for maximum 0.2 % blending tolerance limits.

7.3.2.1 Calculate the mass equivalents of the volumetrically-defined blend components from the densities of the individual components at 15.56 °C (60 °F).

7.4 *Auxiliary Apparatus:*

7.4.1 *Injector Nozzle Tester*—The injector nozzle assembly shall be checked whenever the injector nozzle is removed and reassembled to ensure the initial pressure at which fuel is discharged from the nozzle is properly set. It is also important to inspect the type of spray pattern. Commercial injector nozzle testers which include a lever-operated pressure cylinder, fuel reservoir and pressure gauge are available from several sources as common diesel engine maintenance equipment.

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

8. Reagents and Reference Materials

8.1 *Cylinder Jacket Coolant*—Water shall be used in the cylinder jacket for laboratory locations where the resultant boiling temperature shall be 100 °C ± 2 °C (212 °F ± 3 °F). Water with commercial glycol-based antifreeze added in sufficient quantity to meet the boiling temperature requirement shall be used when laboratory altitude dictates. A commercial multifunctional water treatment material should be used in the coolant to minimize corrosion and mineral scale that can alter heat transfer and rating results.

8.1.1 Water shall be understood to mean reagent water conforming to Type IV of Specification D1193.

8.2 *Engine Crankcase Lubricating Oil*—An SAE 30 viscosity grade oil meeting current API service classification or compatible previous API service classifications shall be used. It shall contain a detergent additive and have a kinematic viscosity of 9.3 cSt

TABLE 2 Specifications for Primary Reference Fuels

Property	Hexadecane	Heptamethylnonane	Pentamethylheptane	Test Method
Purity, mass %, minimum	99.0	98.0	99.5	Gas chromatography
Hydroperoxide number, mg/kg as O, maximum	5.0	5.0	5.0	ASTM D3703

to 12.5 cSt (mm^2 per s) at 100 °C (212 °F) and a viscosity index of not less than 85. Oils containing viscosity index improvers shall not be used. Multigraded oils shall not be used. (**Warning—**Lubricating oil is combustible, and its vapor is harmful. See Annex A1.)

8.3 *Primary Reference Fuels*—(**Warning—**Primary Reference Fuel—Combustible. Vapor harmful. See Annex A1.)

8.3.1 *Hexadecane*—Hexadecane meeting the specifications in Table 2 shall be used as the designated 100 cetane number component.

8.3.2 *Heptamethylnonane* ~~*(2,2,4,4,6,8,8-heptamethylnonane)—*~~*(2,2,4,4,6,8,8-heptamethylnonane)—*Heptamethylnonane meeting the specifications in Table 2 may be used as the low cetane number component that is blended with hexadecane. In binary volumetric blends with HXD, HMN has a cetane number ARV of 15.

8.3.2.1 The cetane number accepted reference value (CN_{ARV}) for any mixture of HXD and HMN is given by the relationship:

$$CN_{ARV} = \text{volume-\% HXD} + 0.15(\text{volume-\% HMN}) \quad (1)$$

8.3.3 *Pentamethylheptane* ~~*(2,2,4,6,6-pentamethylheptane)—*~~*(2,2,4,6,6-pentamethylheptane)—*Pentamethylheptane meeting the specifications in Table 2 may be used as the low cetane number component that is blended with hexadecane. In binary volumetric blends with HXD, PMH has a cetane number ARV of 16.3.

8.3.3.1 The cetane number accepted reference value (CN_{ARV}) for any mixture of HXD and PMH is given by the relationship:

$$CN_{ARV} = \text{volume-\%HXD} + 0.163(\text{volume-\% PMH}) \quad (2)$$

8.3.4 Store and use primary reference fuels at temperatures of 20 °C or higher to avoid solidification of HXD, which has a melting point of 18 °C.

8.4 *Secondary Reference Fuels*—(**Warning—**Secondary reference fuel—combustible. Vapor harmful. See Annex A1.)

8.4.1 *T Fuel*—Diesel fuel meeting the specifications in Table 3.

8.4.2 *U Fuel*—Diesel fuel meeting the specifications in Table 3

8.4.3 Storage and use of *T Fuel* and *U Fuel* should be at temperatures above 0 °C (32 °F) to avoid potential solidification, particularly of *T Fuel*. Before a container that has been stored at low temperature is placed in service, it should be warmed to a temperature of at least 14 °C (26 °F) above its Cloud Point. (See Test Method D2500.) It should be held at this temperature for a period of at least 30 min and then the container should be thoroughly remixed.

8.4.4 As secondary reference fuel blends are rated in numbered pairs, they are not interchangeable with reference fuels from other numbered pairs and shall not be mixed.

8.5 *Check Fuels*[9]—Diesel fuel oils having properties other than CN that are typical of Specification D975 grade No. 2-D S15. (**Warning—**Check Fuel—Combustible. Vapor harmful. See Annex A1.)

8.5.1 *Low Cetane Check Fuel,* meeting the specifications in Table 3.

8.5.2 *High Cetane Check Fuel,* meeting the specifications in Table 3.

[9] Blend Tables for batches of *T Fuel* and *U Fuel* can be obtained from the fuel supplier.

TABLE 3 Specifications for Secondary Reference Fuels and Check Fuels

Property	Secondary Reference Fuels		Check Fuels		Test Method
	T-Fuel	U-Fuel	Low	High	
Cetane number ARV, minimum	73	19	38.	50.	ASTM D613
Cetane number ARV, maximum	76	22	42.	55.	ASTM D613
Hydroperoxide number, mg/kg as O, maximum	5.0	5.0	5.0	5.0	ASTM D3703

9. Sampling

9.1 Collect samples in accordance with Practice D4057 or D4177.

9.1.1 *Protection from Light*—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.

9.2 *Fuel Temperature*—Samples shall be brought to room temperature typically 18 °C to 32 °C (65 °F to 90 °F) before engine testing.

9.2.1 The fuel temperature should be raised at least 14 °C (26 °F) above the fuel's cloud point. The fuel sample should be homogeneous before engine testing or filtration (9.3).

NOTE 1—Give consideration to the fuel's composition related to sample temperature to avoid the loss of any lower boiling components that may affect the cetane rating.

9.3 *Filtration*—Samples may be filtered through a Type I, Class A filter paper at room temperature and pressure before engine testing. See Specification E832.

10. Basic Engine and Instrument Settings and Standard Operating Conditions

10.1 *Installation of Engine Equipment and Instrumentation*—Installation of the engine and instrumentation requires placement of the engine on a suitable foundation and hookup 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.

10.1.1 Proper operation of the test engine requires assembly of a number of engine components and adjustment of a series of engine variables to prescribed specifications. Some of these settings are established by component specifications, others are established at the time of engine assembly or after overhaul, and still others are engine running conditions that must be observed or determined by operator adjustment, or both, during the testing process.

10.2 *Conditions Based on Component Specifications:*

10.2.1 *Engine Speed*—900 r/min ± 9 r/min, when the engine is operating with combustion with a maximum variation of 9 r/min occurring during a rating. Engine speed when combustion is occurring shall not be more than 3 r/min greater than that for motoring without combustion.

10.2.2 *Valve Timing*—The engine uses a four-stroke cycle with two crankshaft revolutions for each complete combustion cycle. The two critical valve events are those that occur near TDC; intake valve opening and exhaust valve closing.

10.2.2.1 Intake valve opening shall occur 10.0° ± 2.5° ATDC with closing at 34° ABDC on one revolution of the crankshaft and flywheel.

10.2.2.2 Exhaust valve opening shall occur 40° BBDC on the second revolution of the crankshaft or flywheel with closing at 15.0° ± 2.5° ATDC on the next revolution of the crankshaft or flywheel.

10.2.3 *Valve Lift*—Intake and exhaust cam lobe contours, while different in shape, shall have a contour rise of 6.223 mm to 6.350 mm (0.245 in. to 0.250 in.) from the base circle to the top of the lobe so that the resulting valve lift shall be 6.045 mm ± 0.05 mm (0.238 in. ± 0.002 in.).

10.2.4 *Fuel Pump Timing*—Closure of the pump plunger inlet port shall occur at a flywheel crank angle between 300° and 306° on the engine compression stroke when the fuel flow-rate-micrometer is set to a typical operating position and the variable timing device lever is at full advance (nearest to operator).

10.2.5 *Fuel Pump Inlet Pressure*—A minimum fuel head established by assembly of the fuel tanks (storage reservoirs) and flow rate measuring buret so that the discharge from them is 635 mm ± 25 mm (25 in. ± 1 in.) above the centerline of the fuel injection pump inlet.

10.3 *Assembly Settings and Operating Conditions:*

10.3.1 *Direction of Engine Rotation*—Clockwise rotation of the crankshaft when observed from the front of the engine.

10.3.2 *Injection Timing*—13.0° BTDC, for the sample and reference fuels.

10.3.3 *Injector Nozzle Opening Pressure*—10.3 MPa ± 0.34 MPa (1500 psi ± 50 psi).

10.3.4 *Injection Flow Rate*—13.0 mL/min ± 0.2 mL/min (60 s ± 1 s per 13.0 mL).

10.3.5 *Injector Coolant Passage Temperature*—38 °C ± 3 °C (100 °F ± 5 °F).

10.3.6 *Valve Clearances:*

10.3.6.1 *Engine Running and Hot*—The clearance for both intake and exhaust valves shall be set to 0.20 mm ± 0.025 mm (0.008 in. ± 0.001 in.), measured under standard operating conditions with the engine running at equilibrium conditions on a typical diesel fuel oil.

10.3.7 *Oil Pressure*—172 kPa to 207 kPa (25 psi to 30 psi).

10.3.8 *Oil Temperature*—57 °C ± 8 °C (135 °F ± 15 °F).

10.3.9 *Cylinder Jacket Coolant Temperature*—100 °C ± 2 °C (212 °F ± 3 °F).

10.3.10 *Intake Air Temperature*—66 °C ± 0.5 °C (150 °F ± 1 °F).

10.3.11 *Basic Ignition Delay*—13.0° for the sample and reference fuels.

10.3.12 *Cylinder Jacket Coolant Level:*

10.3.12.1 *Engine Stopped and Cold*—Treated water/coolant added to the cooling condenser—cylinder jacket to a level just observable in the bottom of the condenser sight glass will typically provide the controlling engine running and hot operating level.

10.3.12.2 *Engine Running and Hot*—Coolant level in the condenser sight glass shall be within ±1 cm (0.4 in.) of the LEVEL HOT mark on the coolant condenser.

10.3.13 *Engine Crankcase Lubricating Oil Level:*

10.3.13.1 *Engine Stopped and Cold*—Oil added to the crankcase so that the level is near the top of the sight glass will typically provide the controlling engine running and hot operating level.

10.3.13.2 *Engine Running and Hot*—Oil level shall be approximately mid-position in the crankcase oil sight glass.

10.3.14 *Crankcase Internal Pressure*—As mentioned by a gauge or manometer connected to an opening to the inside of the crankcase through a snubber orifice to minimize pulsations, the pressure shall be less than zero (a vacuum) and typically from 25 mm to 150 mm (1 in. to 6 in.) of water less than atmospheric pressure. Vacuum shall not exceed 255 mm (10 in.) of water.

10.3.15 *Exhaust Back Pressure*—As measured by a gauge or manometer connected to an opening in the exhaust surge tank or main

FIG. 2 Typical Injector Spray Pattern

exhaust stack through a snubber orifice to minimize pulsations, the static pressure should be as low as possible, but shall not create a vacuum nor exceed 254 mm (10 in.) of water differential in excess of atmospheric pressure.

10.3.16 *Exhaust and Crankcase Breather System Resonance*—The exhaust and crankcase breather piping systems shall have internal volumes and be of such length that gas resonance does not result.

10.3.17 *Piston Over-Travel*—Assembly of the cylinder to the crankcase shall result in the piston protruding above the top of the cylinder surface 0.381 mm ± 0.025 mm (0.015 in. ± 0.001 in.) when the piston is at top-dead-center. Proper positioning is accomplished through the use of plastic or paper gaskets, available in several thicknesses and selected by trial and error for assembly between the cylinder and crankcase deck.

10.3.18 *Belt Tension*—The belts connecting the flywheel to the absorption motor shall be tightened, after an initial break-in, so that with the engine stopped, a 2.25 kg (5 lb) weight suspended from one belt ~~half way~~ halfway between the flywheel and motor pulley shall depress the belt approximately 12.5 mm (0.5 in.).

10.3.19 *Setting Injector Nozzle Assembly Pressure and Spray Pattern Check*—(**Warning—**Personnel shall avoid contact with the spray pattern from injector nozzles because of the high pressure which can penetrate the skin. Spray pattern performance checks shall be made in a hood or where adequate ventilation insures that inhalation of the vapors is avoided.)

10.3.19.1 *Injector Opening or Release Pressure*—The pressure adjusting screw is adjustable and shall be set to release fuel at a pressure of 10.3 MPa ± 0.34 MPa (1500 psi ± 50 psi). Check this setting using an injector nozzle bench tester, each time the nozzle is reassembled and after cleaning. Use of a commercial injector nozzle bench tester is recommended. See Annex A2 for procedural detail.

10.3.19.2 *Injector Spray Pattern*—Check the spray pattern for symmetry and characteristic by inspection of the impression of a single injection made on a piece of filter paper or other slightly absorbent material placed at a distance of approximately 7.6 cm (3 in.) from the nozzle. A typical spray pattern is illustrated in Fig. 2.

10.3.20 *Indexing Handwheel Reading*—Handwheel readings are a simple and convenient indication of engine compression ratio which is a critical variable in the cetane method of test. The actual compression ratio is not important but an indication of compression ratio which relates to cetane number is a useful guide for selecting reference fuels to bracket the sample of diesel fuel oil. The following procedure shall be used to index the handwheel reading when the engine is new or anytime the matched handwheel assembly/cylinder head combination is interchanged or mechanically reassembled.

10.3.20.1 *Handwheel Micrometer Drum and Scale Setting*—Refer to Table 4 to select the appropriate handwheel reading to be used in aligning the drum and scale.

10.3.20.2 *Basic Setting of Variable Compression Plug*—Position the variable compression plug so that the flat surface is just visible and exactly in line with the edge of the threads of the combustion pickup hole, as verified with a straightedge.

10.3.20.3 *Setting Handwheel Reading*—Tighten the small locking handwheel snugly by hand to ensure that the variable compression plug is held in place in the bore. Loosen the ~~lock nut~~ locknut of the large handwheel and remove the locking L-shaped key. Turn the large handwheel so that the edge of the drum is in alignment with the 1.000 graduation on the horizontal scale. Reinstall the L-shaped key in the nearest keyway slot of the large handwheel with the shorter leg in the handwheel. A slight shifting of the handwheel to achieve slot lineup will not affect the indexing. Tighten the ~~lock nut~~ locknut hand-tight to hold the key in place. Remove the locating screw from the drum and rotate the drum so that the zero graduation mark is in line with the selected reading from Table 4. Locate the screw hole in the drum which lines up with the handwheel hub hole and reinstall the locating screw.

TABLE 4 Handwheel Setting for Various Cylinder Bore Diameters

Cylinder Diameter, in.		Handwheel Reading
3.250	(Standard Bore)	1.000
3.260	(Rebored 0.010 in. Oversize)	0.993
3.270	(Rebored 0.020 in. Oversize)	0.986
3.280	(Rebored 0.030 in. Oversize)	0.978

Wrench tighten the large handwheel ~~lock nut~~ locknut and recheck that the variable compression plug is properly positioned and the handwheel reading is in accordance with the value in Table 4.

10.3.21 *Basic Compression Pressure*—At a handwheel reading of 1.000, the compression pressure for an engine operated at standard barometric pressure of 760 mm Hg. (29.92 in. Hg) shall be 3275 kPa ± 138 kPa (475 psi ± 20 psi) when read as quickly as possible after shutdown of the engine which had been at standard operating conditions. If the condition is not within limits, recheck the basic handwheel setting and, if necessary, perform mechanical maintenance. See Annex A2 for the Checking Compression Pressure procedure.

10.3.21.1 For engines operated at other than standard barometric pressure, the compression pressure will typically be in proportion to the ratio of the local barometric pressure divided by standard barometric pressure. As an example, an engine located where the barometric pressure is 710 mm Hg would be expected to have a compression pressure of approximately 3060 kPa ± 138 kPa (444 psi ± 20 psi). (**Warning—**In addition to other precautions, compression pressure testing using a compression pressure gauge should be completed in as short a period of time as possible to avoid the possibility of combustion occurrence due to the presence of any small amount of oil in the gauge or combustion chamber.)

~~$$\text{Compression Pressure}_{(LocalBaro.,mmHg)} = 3275\text{ kPa} \times \text{Local Baro./Standard Baro.} \quad (3)$$~~

~~$$\text{Example:Compression Pressure}_{710mmHg} = 3275 \times 710/760 = 3060\text{ kPa}$$~~

$$\text{Compression Pressure}_{(LocalBaro.,mmHg)} = 3275\text{ kPa} \times \text{Local Baro./Standard Baro.} \quad (3)$$

$$\text{Example:Compression Pressure}_{710mmHg} = 3275 \times 710/760 = 3060\text{ kPa}$$

10.3.22 *Fuel Pump Lubricating Oil Level*—With the engine stopped, sufficient engine crankcase lubricating oil shall be added to the pump sump so that the level is at the mark on the dip stick. (**Warning—**As a result of engine operation, especially when the pump barrel/plunger assembly begins to wear, the level in the sump will increase due to fuel dilution as observed through a clear plastic side plate on the pump housing. When the level rises appreciably, the sump should be drained and a fresh charge of oil added.)

10.3.23 *Fuel Pump Timing Gear Box Oil Level*—With the engine stopped, unplug the openings on the top and at the mid-height of either side of the gear box. Add sufficient engine crankcase lubricating oil through the top hole to cause the level to rise to the height of the side opening. Replug both openings. (**Warning—**The pump and timing gear box oil sumps are not connected to each other and the lubrication for the two is independent.)

10.3.24 *Instrumentation*—Positioning of the reference pickups and injector pickup is important to ensure that timing of the injection and ignition delay functions is uniform and correct.

10.3.24.1 *Setting Reference Pickups*—These two pickups are identical and interchangeable. They are installed in a bracket positioned over the flywheel so that they clear the flywheel indicator which triggers them.

10.3.24.2 Position each pickup in the bracket so that it is properly referenced to the flywheel indicator in accordance with the instructions supplied with the specific pickup.

10.3.24.3 Measurement of pickup to flywheel indicator clearance, if required, shall be made using a nonmagnetic feeler gauge.