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Reciprocating Internal - Combustion Engines

PERFORMANCE
TEST
CODES

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
United Engineering Center
345 East 47th Street New York, N.Y. 10017

Reciprocating Internal - Combustion Engines

PERFORMANCE TEST CODES

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FOREWORD

This Code is intended for tests of all types of reciprocating internal-combustion engines for determining power output and fuel consumption. It is not intended for general or specialized research or for development of equipment or processes.

This Code purposely excludes any rating standards, as being neither pertinent to a Performance Test Code nor essential to test procedures.

This Code follows the format specified by PTC 1: Object and Scope, Definitions and Descriptions of Terms, Guiding Principles, Instruments and Methods of Measurement, Computation of Results. In addition, supplementary information is included as an Appendix (Section 7). To make this Code comprehensive yet brief, pertinent portions of other codes and standards are appropriately referenced, rather than duplicate such standards herein.

The original Test Code for Internal-Combustion Engines was published in 1901. Subsequent revisions were adopted in 1915, 1924, and 1929. Extensive revisions were begun in 1939, culminating in an issuance of 1949. This was reaffirmed in 1952, then modified slightly in 1957 and again reaffirmed. Because of developments in the industry and in pertinent measurement techniques, and because other pertinent codes had been developed in the interim, need was seen for total review and revision of PTC 17. Work was begun in 1966 resulting in this entirely new Code.

This Code was approved by the Performance Test Codes Committee on January 15, 1973 and approved and adopted by the Council of the Society by action of the Policy Board on Codes and Standards on February 28, 1973.

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ASME PERFORMANCE TEST CODES

RECIPROCATING INTERNAL-COMBUSTION ENGINES

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SECTION 1, OBJECT AND SCOPE

1.1 Purpose

1.1.1 This Code provides rules for testing, and for the computation and tabulation of the results of tests, for all types of reciprocating internal-combustion engines, in order to determine power and fuel consumption. (See Par. 7.1.1)

1.2 Object

1.2.1 The objects of testing under this Code are the determination of:

(a) Net power output; and

(b) Rate of fuel consumption and/or energy input, as defined in Section 2. (Attention is directed to the fact that energy input is based on the low heat value of the fuel.)

1.2.2 Only tests made in accordance with the provisions of this Code may be designated as complying therewith.

1.2.3 For procedures to attain optional test objectives, related codes or standards must be consulted. (See Par. 7.1.2.3)

1.2.4 With respect to any tests to verify performance, the objects and procedures of the tests shall be agreed upon and shall be defined clearly and exactly, in writing, before tests are started.

1.3 Scope

1.3.1 Application of this Code is limited to engine assemblies as defined in Pars. 1.3.2 and 1.3.3.

1.3.2 Code Engine Assembly. In the absence of specified stipulations the engine assembly to be tested shall consist of the engine complete with essential apparatus for self-sustained continuous operation. Generally these consist of the equipment required for: fuel introduction; air induction (i.e., scavenging or supercharging); ignition; lubrication; and primary engine and charge-air cooling. This is termed the "Code Engine Assembly."

1.3.2.1 Specifically, a "Code Engine Assembly" includes apparatus: a) to control, carburet or inject fuel delivered to it at required operating supply pressure, including booster fuel supply pump or compressor when attached to engine; b) to provide injection air or gas (if engine is of the air- or gas-injection type); c) to compress intake air; d) to provide ignition; e) to circulate lubricating oil throughout the engine lubricating system, including oil cooler, strainers, filters and mechanical force feed supply; and f) to circulate the primary coolants through the engine jackets, lubricating oil coolers, and intake air coolers - all as involved in the engine assembly being tested.

1.3.2.1.1 If any apparatus required for the above functions is driven by a separate source of power, the power input to, or the fuel consumed by, the driving unit shall be charged against the "Code Engine Assembly." If any apparatus, systems or parasitic load not included in the "Code Engine Assembly" (such as an intake filter, exhaust silencer, or radiator system) is attached to or driven by the engine, it should be detached during engine tests, or, if detachment is not practicable, the power consumed thereby shall be separately determined or agreed upon and credited to the "Code Engine Assembly" power output.

1.3.2.2 The "Code Engine Assembly" does not include any apparatus for starting, battery charging, or other purpose which does not function continuously, nor any apparatus for other purposes not mentioned here.

1.3.3 Specified Engine Assembly (See Par.7.1.3.3)

1.4 Performance Conditions

1.4.1 Every effort shall be made to conduct each test run on the basis of specified operating conditions. The maximum permissible deviations therefrom shall not exceed the limits prescribed in Par. 3.4.4 and in Table 1 except by special agreement.

1.5 Tolerances

1.5.1 Tolerances or margins to allow for inaccuracies in tests, which may be directly applied to the final result, are outside the scope of the ASME Performance Test Codes. Such tolerances or margins are chiefly of commercial significance and are to be settled by agreement between the parties to a contract. Limits of error in instruments or methods of measurement may be stated in the codes, but exact limits should be stipulated preferably in a contract or agreed upon prior to the acceptance test.

SECTION 2, DESCRIPTION AND DEFINITION OF TERMS

Par. No.	Term	Symbol	Description	Unit FPS	Unit SI
2.1			Power		
2.1.1	Measured power output, mechanical	P_{mg}	Power delivered at the coupling power take-off connection of any of the engine assemblies defined in this Code, as determined by a "dynamometer" or other approved measuring device, expressed as "brake power" (Ref. PTC-19.7)	hp*	kW**
2.1.2	Correction for auxiliaries and accessories, charges and credits, mechanical	Y_1	Net brake power quantity subtracted from (or added to) measured power output, mechanical, when correcting for power incidental to separately driven auxiliaries or abnormal accessories as prescribed in Par. 5.2.2.	hp	kW
2.1.3	Net power output	P_{mn}	Power determined from the measured power output, mechanical, by application of charges and credits.	hp	kW
2.1.4	Indicated power	P_{mi}	Power exerted by the working medium in the cylinders or an engine assembly, as obtained by calculation based on the indicated mean effective pressure, or by summation of the net power output, mechanical and the total power losses including friction power (Ref. PTC-19.8).	hp	kW
2.1.5	Measured power output, electrical	P_{eg}	Power delivered at the generator terminals of any of the engine driven generator units defined in this Code, as determined by electrical measurements (Ref. PTC-19.6).	kW	kW
2.1.6	Correction for auxiliaries and accessories, charges and credits, electrical	Y_2	Net kilowatt quantity subtracted from (or added to) to measured power output, electrical, when correcting for power incidental to separately driven auxiliaries or abnormal accessories as prescribed in Par. 5.3.2.	kW	kW

*Under the "FPS" system "horsepower" is the recognized term for power and one "hp" equals 550 ft-lb/sec or 746 newton – metre/sec.

**Under the "SI" system "watts" or "kilowatts" are the recognized terms for power and one " kW" equals 1000 newton – metre/sec.

DESCRIPTION AND DEFINITION OF TERMS (CONT'D)

Par. No.	Term	Symbol	Description	Unit FPS	Unit SI
			Power (Cont'd).		
2.1.7	Corrections for cable losses, separately supplied generator excitation and ventilation	Y_3	Net kilowatt quantity subtracted from (or added to) to measured power output, electrical, at the generator terminals for cable losses and conditions of separately supplied generator excitation and ventilation as involved for specific test as prescribed in Par. 5.3.1.	kW	kW
2.1.8	Net power output, electrical	P_{en}	Power determined from the measured power output, electrical, by application of charges and credits as prescribed in this Code.	kW	kW
2.1.9	Watthour meter constant, primary	PK_h	Watthour per disc revolution of watthour meter.	Wh/rev	Wh/rev
2.2			**Pressures**		
2.2.1	Specified pressure	p_s	Specified absolute pressure of gas when reporting heating values.	psia	Pa*
2.2.2	Gas pressure @ meter (gaseous fuel)	p_m	Absolute pressure of gaseous fuel measured at intake of the metering device used for measuring the fuel quantity.	psia	Pa
2.2.3	Indicated mean effective pressure	p_i	The indicated mean effective pressure (IMEP) is that pressure which, assumed as acting at constant magnitude on the piston, would produce or absorb during one piston stroke an amount of work equal to that produced or absorbed during one complete working cycle by the actually-occurring variable pressure. The indicated mean effective pressure may also be defined as the indicated work of one complete cycle, divided by the piston displacement in which this work was done.	psi	Pa
2.2.4	Water vapor pressure	p_w	The partial pressure of the water vapor in the gas at the point when the pressure p_m was measured. This value will vary with the temperature and percentage of saturation.	psi	Pa

*One Pa ("pascal") equals one "newton/m^2".
One psi equals 6894.757 pascals (see ASTM E–380).

Par. No.	Term	Symbol	Description	Unit FPS	Unit SI
2.3			**Temperatures**		
2.3.1	Fuel temperatures (gaseous fuels)	T_m	Absolute temperature of gaseous fuel measured at intake of the metering device used for measuring fuel quantity.	°R (°F+459.7)	°K (°C+ 273.2)
2.3.2	Specified temperature	T_s	Specified absolute temperature of gas when reporting heating values.	°R (°F+459.7)	°K (°C+ 273.2)
2.4			**Time**		
2.4.1	Rotation watt-hour meter	r_w	Time for r_d watthour-meter disc turns.	sec	s
2.4.2	Rotation, watt-hour meter	r_d	Arbitrarily chosen number of watt-hour-meter disc turns.	rev	rev
2.4.3	Minute	min	Used in some equations in Section 5.	min	min
2.4.4	Hour	h	Used in some equations in Section 5.	h	h
2.4.5	Test run period	r_{o_1} r_{o_2} r_{o_3}	Duration of individual test time: 1) Power measurement 2) Liquid fuel measurement 3) Gaseous fuel measurement	sec	s
2.5			**Speed**		
2.5.1	Observed speed	n	Sustained governed speeds under steady-state operating conditions as observed during test periods r_{o_1}, r_{o_2}, r_{o_3}	rpm	rpm
2.6			**Volume and Weight**		
2.6.1	Total gas quantity measured at meter	V_m	Volume of gaseous fuel supplied to the engine during test period r_{o_3} as measured at meter.	cu ft	m^3
2.6.2	Total liquid fuel consumption, as measured	W_2	Weight of liquid fuel supplied to the engine during test period r_{o_2}.	lb	kg

Par. No.	Term	Symbol	Description	Unit FPS	SI
2.7			Heat Quantities		
2.7.1	Heat value, gaseous fuel	Q_g	Low unsaturated heat value of gaseous fuel used for the test, at specified conditions.	Btu/cu ft @p_s & T_s	J/m^3 @p_s & T_s
2.7.2	Heat value, liquid fuel	Q_k	Low-heat value of liquid fuel used for the test.	Btu/lb	J/kg
2.7.3	Net specific energy consumption	q_a	Energy consumption of an internal combustion engine referred to net power output, mechanical, and based on low unsaturated heat value of the fuel used for the test.	Btu/hph	J/kWh
2.7.4	(Same)	q_b	Same as q_a but based on net power output, electrical.	Btu/kWh	J/kWh
2.8			General		
2.8.1	Torque, gross	F_g	Turning moment measured or computed at the engine coupling or power take-off connection.	lb ft	N·m
2.8.2	Compressibility factor	Z	Factor from equation $PV=ZRT$ to correct for non-ideal gas behavior.	non-dimensional	
2.8.3	Generator efficiency, conversely accounting for losses in the generator unit.	η	A value representing the ratio of generator output divided by the generator input when both these values are expressed in similar terms.	non-dimensional	

SECTION 3, GUIDING PRINCIPLES

3.1 Limits of Code

3.1.1 Procedures established in Section 3 and 4 of this Code are limited to tests establishing net power output and energy consumption (as defined in Section 2) for reciprocating internal-combustion engines. Test procedures for all other objectives must be by special agreement.

3.2 Agreements

3.2.1 Agreements Before Tests. Prior to testing, the parties to the tests shall reach definite agreement on items such as the following (see pertinent paragraphs as noted):

(a) Specific objects of the tests. (Par. 1.2)
(b) Clarification of any ambiguities or conflicts within specifications and their intent, or between specification and Code procedures.
(c) Designation of arbiter on necessary decisions during test. (Par. 3.3.4.1).
(d) Place where tests are to be conducted. (Par. 7.3.2.1 d)
(e) When tests are to be run.
(f) Preliminary tests to verify readiness for final tests. (Pars. 3.3.1 and 3.3.2)
(g) Designation of official test witnesses and their responsibility and authority. (Par. 3.3.4)
(h) Selection and organization of other test party personnel, including designation of the test director. (Pars. 3.3.4.1 and 3.3.4.2)
(i) Records to be maintained and responsibility therefor. (Par. 3.5)
(j) Number of copies of original data required and to whom to be furnished. (Par. 3.5.2.1)
(k) Source of load for engine test and responsibility for providing it. (Par. 3.3.5)
(l) Means of adjusting for auxiliary loads to be included in or excluded from engine assembly. (Pars. 1.3.2., 1.3.3, and Section 5)
(m) Fuel and other operating supplies to be used for test, including source, characteristics, and the party responsible for providing. (Par. 3.4.1)
(n) Designation of laboratory qualified for determining pertinent fuel characteristics and choice of Code method for such determinations. (Section 4)
(o) Provisions for and designation of all instruments to be employed; arrangements for conditioning and calibrating instruments; special calibration agreements; limits of possible measurement error. (Par. 3.3.5 and Section 4)
(p) Maximum permissible variations in operating conditions if these exceed the values stated in Table 1. (Par. 3.4.2 and 3.4.4)
(q) Numerical values (if needed) for test corrections or adjustments not elsewhere covered in the Code.
(r) Duration of tests and general provisions for operating engine throughout the testing period. (Pars. 3.4.1, 3.4.5 and 3.4.6)
(s) Methods of maintaining constant operating conditions within deviations allowed in Table 1 and agreed to under (p) above.
(t) Engine control and permissible adjustments to controls during tests. (Par. 3.4.1)
(u) Method of determining stable operation before test readings are started. (Par. 3.4.1.2)
(v) Provisions for starting and stopping each test run. (Par. 3.4.5)
(w) Number of observations. (Par. 3.4.6.1)
(x) Methods of computing results. (Section 5)

3.2.2 Other Agreements. This Code and the agreements called for above specify the procedures and calculations necessary to test for the primary objects hereof (net power output and rate of fuel consumption and/or energy input) within limitations established in this Code. In addition, agreements should specify loads and speeds at which tests are to be run and means of fuel measurement. In the absence of written agreement, Code procedures shall be mandatory.

3.3 Preparation for Tests

3.3.1 Preliminary Operation and Adjustment. Before the tests, the engine assembly first shall be put in adjustment and be operated for sufficient time to condition it to perform in a normal manner, so that test results will be a measure of actual performance under stipulated or agreed conditions of the tests.

3.3.1.1 The nature and extent of running-in prior to formal test shall be determined from preliminary observations and all parties to the test shall be given an opportunity to make an examination to determine that the engine is in condition for testing. Following this, agreement for proceeding with the formal test is necessary; the test director shall decide any disagreement on this point.

3.3.2 Preliminary Tests. It is recommended that preliminary tests be run for the purposes of checking instruments and for determining that the engine is ready for final tests. If mutually agreed upon, such test may be considered as an ASME Code test, provided it has complied with all the requirements for such a test.

3.3.3 Equipment Inspection. Prior to conducting the tests, all facilities and instruments related to (or to be excluded from) the engine assembly shall be inspected by the test director to assure compliance with this Code and with any preliminary agreements. All parties to the test may participate in this inspection. All conditions noted shall become part of the permanent test record. (See Par. 3.5.1)

3.3.4 Selection of Test Personnel. The composition of the test operating personnel shall be the responsibility of the party at whose facilities the engine assembly is to be tested. Designated witnesses of parties to the test may be present at all times during the tests to verify that they are conducted in accordance with this Code and any other agreements.

3.3.4.1 A single individual shall be designated "test director," with authority and responsibility to determine readiness for testing, to initiate and halt test runs, to certify compliance with proper test procedures, and to arbitrate necessary decisions during the test. He also shall be responsible for calculation of and reporting on test results.

3.3.4.2 Prior to testing, parties to the test shall designate official witnesses to the tests who shall have definitive authority in reaching agreement, before and during tests, on test procedures.

3.3.5 Test Apparatus. If no agreement has been reached on responsibility for providing and calibrating necessary test load and apparatus, this shall be the responsibility of the party at whose facilities the engine assembly is to be tested. Apparatus shall comply with this Code or as otherwise agreed to by the parties to the test.

3.4 Operating Conditions

3.4.1 General. Fuel and supplies and all operating conditions shall be as nearly as possible in accordance with the manufacturer's recommendations and applicable specifications. The engine shall be controlled by its normal operating devices in simulation of normal operation. It shall be operated during all test runs at each test point without manual adjustments to controls, but controls may be adjusted between test points (unless the applicable specifications prohibit such manual adjustments).

3.4.1.1 No special provisions or adjustments may be made to the engine assembly for purposes of the tests that could prevent or limit immediate, continuous and reliable operation at all capacities or outputs under specified normal operating conditions.

3.4.1.2 Preparatory to any test, the engine assembly shall be run for a time sufficiently long to establish a steady state or operating condition where power output, speed, jacket and lubricating-oil temperatures, and fuel- or heat-consumption rates remain essentially constant. The test cannot be started until a steady state has been attained for the conditions under which the test is to be run, and until preliminary observations prove that such steady state has been reached. Length of time necessary to establish the steady state will vary for engines of different classes, and vary in any one class for different sizes.

3.4.1.2.1 If successive runs are to be made, each under different conditions, the conditions of steady state shall be established for each test run and proved by suitable preliminary observations for each run.

3.4.2 Atmospheric Conditions. The engine assembly shall be tested at the specified atmospheric conditions, within deviation limits in Table 1 (as may be modified by preliminary agreements in cognizance of the impracticability of simulating atmospheric conditions.)

3.4.3 Fuel Conditions and Energy Consumption Rates. All energy consumption rates shall be based upon the net (low heat) value of the fuel under conditions of "as received." Fuel conditions for testing shall conform to specifications within limits of deviation in Table 1. (See Par. 7.3.4.3)

3.4.4 Permissible Deviations in Operating Conditions. Each observation of an operating condition during a test run shall not deviate from the reported average for that operating condition during the complete run by an amount more than that shown in the second column of Table 1. Each reported average operating condition during a test run shall not deviate from the specified operating condition by an amount more than that shown in the third column of Table 1. If any test run, or the average operating condition, deviates beyond the limits prescribed in Table 1, the test run or entire test conditions shall be discarded.

3.4.5 Starting and Stopping of Tests. Measurements for power output and related fuel consumption on individual test runs should be started and stopped virtually simultaneously. However, as long as loads are stable and instrument readings are recorded frequently during a test, it is not essential to observe simultaneously those readings which are made at the same intervals. Where the weighted average of a series of readings is used in calculating results, uniform time periods, adapted to conditions of the test and nature of data required, may be employed rather than attempting simultaneous readings of all items.

3.4.5.1 Such procedures should be part of the preliminary agreements. Care should be exercised that such procedures could not conceivably affect the resultant calculated fuel consumption rates per unit of power output by over ± 1.0 percent.

3.4.6 Duration of Tests. Unless specified otherwise, no series of runs on fuel consumption tests at a load point shall exceed a period of three hours nor be less than one hour. (If longer periods are agreed to, special agreements must be reached on permissible deviations in conditions under Table 1 and/or on corrections therefor.)

3.4.6.1 There shall be a minimum of three test runs at each test point (for power output and/or fuel consumption). The computed result shall be the time-weighted average of related readings.

3.5 Records

3.5.1 Prior to Test. Prior to the tests, a record should be made of at least the following items:

(a) All preliminary agreements.
(b) All items included and excluded from the "engine assembly" and the agreed correction values therefor, if any. (See Pars. 1.3.2 and 1.3.3)
(c) Serial numbers and nameplate data of facilities and auxiliaries under test.
(d) Layout of equipment under test or related thereto, with pertinent dimensions.
(e) All test instruments. (A full nameplate description with accuracies, repeatabilities, orifice sizes, deadweight corrections, etc.)
(f) Engine assembly operating hours at start of tests.
(g) Observation of physical conditions of equipment and site.

3.5.2 During Test. A log of all observations made during the tests shall be entered in the test records. The records shall show that stability had been achieved at the start of each series of test runs at new load or speed points.

3.5.2.1 All observations and notations shall be carefully recorded in legible form and sufficient authenticated copies made so that a copy may be given to each interested party to the test. All official copies of the records shall be signed by the respective witnesses and countersigned by the person in charge of each shift or test.

3.5.2.2 Records made before, during and after each test run shall show the extent of fluctuations of conditions and observations in order that data may be available for determining compliance with the limits of deviations.

3.5.2.3 Observations critical to the test shall be noted and recorded in duplicate by two witnesses and readings should be compared and an agreement reached soon after the observations are made. Alternatively, readings should be made by two observers, recorded on a single log, and initialed by both.

3.5.2.4 Every event connected with the progress of a test shall be recorded on the test log sheets together with the time of occurrence and name of the observer. Particular care shall be taken to record any adjustments made to any equipment under test, whether made during a run or between runs. The reason for each adjustment shall also be stated in the test log. Likewise, all indications of distress or instability in the engine assembly shall be noted.

3.5.3 After Test. Upon completion of the test series, a record shall be made of observed performance and site conditions, or changes from initial conditions, such as might affect the evaluation of engine performance.

3.6 Rejection of Tests

3.6.1 Should serious inconsistencies arise, either during a test or during the computation of results from a series of tests, the test or tests shall be rejected, in whole or in part, and the test or test runs repeated as required to comply with the objects of the tests. Whenever the results show insufficient power or other malfunctioning of the engine, the difficulty shall be investigated and its cause corrected, after which the whole test series (such as might be affected by the adjustments) shall be repeated.

Table 1 – Maximum Permissible Deviations in Test Conditions[a]

Variable Operating Condition	Deviation of Any Individual Observation From Reported Average Operating Condition or Value During a Test Run	Deviation of Reported Average Operating Condition During a Test Run From Specified Test Condition or Value
(a) Power output – mean (for rated output or fractional loads)	± 3 percent	± 5 percent
(b) Torque	± 2 percent	± 3 percent
(c) Rotative speed	± 1 percent	± 2 percent
(d) Barometric pressure at site	± 1 percent	No limit
(e) Ambient air intake temperature	± 5 degrees F (2.8°C)	± 5 degrees F (2.8°C)
(f) Relative humidity of air at ambient air intake	No limit	No limit
(g) Water vapor pressure in gaseous fuel [b]	No limit	No limit
(h) Heat value – liquid fuel, per pound (or per kg)	± 0.5 percent	± 3 percent
(i) Heat value – gaseous fuel, per cubic foot [c] (or per cubic meter)	± 2 percent	± 6 percent
(j) Gaseous fuel constituents[c]	± 5 percent of each individual constituent	± 5 percent of each individual constituent
(k) Gas pressure (absolute), as supplied to meter	± 2 percent	+ 10 percent, – 0 percent
(l) Gas temperature, as supplied to meter	± 5 degrees F (2.8°C)	No limit
(m) Exhaust back pressure, at engine (turbocharger outlet, if so equipped)	Not applicable	+ 0 percent, – not below ambient
(n) Intake air pressure drop, from ambient to engine (to blower or supercharger inlet, if so equipped)	Not applicable	+ 0 percent, – no limit

[a] The limits shown in Table 1 specify maximum permissible variations without invalidating a test run or series of runs. If because of valid circumstances the actual test conditions differ from the specified test conditions (or average conditions of a series of runs) by an amount larger than that shown in Table 1, the parties may agree to a method of correcting the results therefor, which should become a part of the test agreements. If such a condition is anticipated for engines for which correction factors are not well established (such as turbocharging), it is suggested that correction for the engine being tested be established on the test floor, where possible.

[b] While correction is appropriate if moisture exists, "pipeline" gas usually contains minor amount of moisture and correction may be omitted in most cases. (See Par. 4.11.5.3)

[c] Varying constituents (especially "heavy ends") can present problems in maintaining proper combustion.

SECTION 4, INSTRUMENTS AND METHODS OF MEASUREMENT

4.1 General

4.1.1 This section describes the instruments, methods, and precautions that shall be employed in testing reciprocating internal-combustion engines under this Code. Alternative test methods are included in some cases. For procedure to obtain some of the supplementary information, other authoritative codes and standards are cited and shall be considered as part of this Code. (See PTC 19 series on Instruments and Apparatus.)

4.2 Classification of Measurements

4.2.1 In preparing a list of measurements to be made preparatory to selection of instruments it should be noted that the measurements required fall into these groups:

4.2.1.1 Measurements required for determination of the primary objects under this Code; i.e., net power output, and rate of fuel consumption and/or energy input.

4.2.1.2 Measurements to indicate maintenance or variation of important operating conditions defined as the steady state required for the test prescribed, but which measurements do not themselves enter into the test results except as showing conditions under which such results were obtained.

4.2.1.3 Measurements for one or more determinations required for such optional tests as may be the subject of agreement by parties to the tests.

4.3 Calibration of Instruments and Apparatus

4.3.1 Instruments and apparatus used for primary object or optional determinations under this Code shall be so calibrated that parties to the test are agreed that all instruments and apparatus are accurate within the stipulated limits of possible error. Methods specified in the PTC 19 series shall govern as to methods of calibration.

4.4 Check List of Instruments and Apparatus Required for Primary-Object Determinations

4.4.1 Tests for the primary objects under this Code require the appropriate use of the following instruments and apparatus:

4.4.1.1 Engine Mechanical Power Output Measurement

4.4.1.1.1 For direct determination of mechanical power output of an engine, a calibrated dynamometer of a type suitable for the engine and the circumstances of the tests (PTC 19.7), having a maximum inaccuracy of ±1.0 percent, shall be used. (For other acceptable means of torque measurement see PTC 19.7 for types and related accuracies.)

4.4.1.1.2 For indirect determination of mechanical power output of an engine-driven generator unit, a calibrated generator and various electrical meters are required. (See PTC 19.6 and ANSI C50.2 and C50.4) Maximum inaccuracy: calibrated generator, ±1.0 percent.

4.4.1.1.3 For other indirect determinations of mechanical power output of engines, under circumstances not permitting use of a dynamometer or calibrated generator, such as compressor drives or commercial generators, other less accurate methods must be employed. (See Par. 7.4.4.1.1.3)

4.4.1.2 Fuel Quantity Measurements

4.4.1.2.1 For a liquid-fuel engine, appropriate tanks with weighing scales, for determination of fuel weights (see PTC 19.5.1). Maximum inaccuracy: ±1.0 percent.

4.4.1.2.2 For a gaseous-fuel engine, a suitable flow (volume) measuring device:

4.4.1.2.2.1 Rotary positive displacement volumetric meter (ASME "Fluid Meters" Part II). Maximum inaccuracy: ±2.0 percent.

4.4.1.2.2.2 Sharp-edge orifice, Venturi, or flow nozzle (ASME "Fluid Meters" Part II). Maximum inaccuracy: ±1.5 percent.

4.4.1.3 Fuel Heating Value (Btu or Joule determination)

4.4.1.3.1 Liquid Fuel: LHV – Bomb Calorimeter (ASTM D-2382). Maximum inaccuracy: ±0.5 percent.

4.4.1.3.2 Gaseous fuel:

4.4.1.3.2.1 Constituent analysis for heating value and specific gravity calculations by mass spectrometer (ASTM D-2650, D-1137). Maximum inaccuracies: ± 1.0 percent; or by

4.4.1.3.2.2 Gas chromatograph (ASTM D-1945, D-1946, D-2163). Accuracy: ± 1.0 percent; plus

4.4.1.3.2.3 Check HHV, saturated, by recording calorimeter test (ASTM D-1826). Maximum inaccuracies: ± 1.0 percent. (See Par. 4.11.5.3 for explanation)

4.4.1.3.2.4 Water vapor content: (ASTM D-1142). Sufficient maximum inaccuracies: ± 5.0 percent.

4.4.1.3.2.5 See Par. 7.4.11.6 for specific constants of heating values and specific gravities for fuel constitutents and Par. 4.11.5 for additional comments.

4.4.1.4 Temperature measurements: For techniques, instrumentation, and maximum inaccuracies, see PTC 19.3.

4.4.1.5 Pressure·measurements: For techniques, instrumentation, and maximum inaccuracies, see PTC 19.2.

4.4.1.6 Speed measurements: For techniques, instrumentation, and maximum inaccuracies; see PTC 19.13.

4.4.1.7. Time measurement: For techniques, instrumentation, and maximum inaccuracies, see PTC 19.12.

4.5 Measurements for Primary Object, General

4.5.1 The power output of any of the engine assemblies, as defined in Pars. 1.3.2 and 1.3.3, may be measured either at the engine coupling with a dynamometer or at the electric-output terminals of a calibrated direct-connected generator.

4.6 Power-Output Measurements, Direct

4.6.1 The net power output of an engine-assembly (as specified in Par. 1.3) is expressed in power referred to the engine coupling and shall include adjustments in output incidental to any power absorbing auxiliaries or accessories as prescribed in Par. 1.3.

4.6.2 The power output of an engine, when measured directly, shall be determined by an absorption or a torsion-transmission dynamometer in connection with rotative speed observations. In each case, the dynamometer shall be directly connected to or mounted on the shaft of the engine. The dynamometer shall be carefully balanced before and after the test. (Further information concerning dynamometers is given in PTC 19.7.)

4.6.3 For absorption dynamometers the torque-arm force shall be measured along a tangent to the torque-arm circle, at the point of application to the weighing means, and acting normal to the line of the force measurement. The maximum inaccuracies in making torque measurements by absorption dynamometers shall be within:

± 0.2 percent – for effective length of torque arm
± 0.2 percent – for amount of torque arm force

4.6.3.1 Links, struts, or levers connecting dynamometers to weighing means shall be essentially free of friction. Flow of water or air used for the dynamometer operation or cooling, and any electrical or hose connections, shall be so arranged as to introduce no appreciable tangential force reactions on the external parts of the dynamometer.

4.6.4 In case of a torsion-transmission dynamometer, the scale of the torsional member shall be calibrated before and after the test, to a maximum inaccuracy of 0.5 percent. Readings for speed shall be taken simultaneously with the deflection readings.

4.7 Rotative Speed Measurements

4.7.1 Depending on conditions of the test, any of the revolution counters or speed indicators listed in Par. 4.4.1.6 may be employed for determining the rotative speed of the engine.

4.7.2 In cases where the mean rotative speed measurement directly influences the test results, the instrument shall be of the revolution counter type. The maximum inaccuracies in counting revolutions and in measuring time intervals shall be such that the resultant rotative speed shall be within ± 0.2 percent. An instrument of the speed-indicating type may be used for initial setting of the test speed and for checking constancy of speed during test periods. (Further information concerning measurement of speed is contained in PTC 19.13, Measurement of Rotary Speed.)

4.8 Power-Output Measurements, Indirect

4.8.1 The net power output of an engine-driven calibrated generator with engine assembly (as specified in Par. 1.3) shall be obtained from electrical measurements suitable for determining the performance in kilowatts referred to the generator terminals and shall include adjustments in output incidental to any power absorbing auxiliaries or accessories as in Par. 1.3 and any deductions, expressed in kilowatts, for power that is separately supplied for generator excitation or ventilation, as prescribed in Par. 1.3. If generator cooling fans are separately driven, energy to the motors shall be deducted from the generator output.

4.8.2 Power-factor must be maintained at specified and calibrated values, or agreement reached for adjustments to results. (See Par. 7.4.8.2)

4.8.3 Instruments for Electrical Output Tests. For three-phase, three-wire a-c generators, power output shall be measured by a polyphase wattmeter with two current coils and two potential coils, or by a two-element watthour meter or by two single-phase watthour meters. For three-phase, four-wire a-c generators, power output shall be measured by a polyphase wattmeter with three current coils and two potential coils, or by a three-element watthour meter or by three single-phase watthour meters. Power output of single-phase a-c generators shall be measured by a single-phase wattmeter or by a single-element watthour meter. Power output of d-c generators shall be measured by the d-c voltmeter-ammeter method.

4.8.3.1 Wattmeters are to be used *only* under conditions of constant power output.

4.8.3.2 Portable indicating ammeters and voltmeters shall be installed in the measuring circuits to establish that generator outputs and, if involved, power factors conform to the specified conditions.

4.8.4 Meters used for measuring electrical power output shall be calibrated and adjusted either in an approved laboratory or in place by use of portable calibration instruments. After such calibrations and adjustments, the instrument accuracy shall equal that established by the instrument manufacturer. (For additional information refer to PTC 19.6)

4.9 Power-Output Measurements, Other Indirect

(See Pars. 7.4.4.1.1.3 and 7.4.9)

4.10 Fuel Consumption, Liquid Fuels

4.10.1 Liquid fuel consumption quantities shall be determined by direct weighing means as the fuel is supplied to the test and shall have a maximum inaccuracy of ± 1.0 percent. Meters or volumetric means for determining quantities shall not be used, except by special agreement between parties to the test. If meters are used, temperature corrections must be applied.

4.10.2 Arrangement of weighing tanks and all connections at tanks shall be such that nothing will influence weight observations except the tank and the contained fuel. After fuel weight determination, there should be no spilling or losses by leakage or by evaporation, as when using volatile fuels or heavy fuels which must be heated and which contain lighter fractions. Fuel drippings shall be credited to engine fuel consumption quantities, but care shall be taken to collect only for the time of the fuel consumption quantity measurements.

4.10.3 For these measurements time shall be determined accurately. (For detailed information, see PTC 19.12)

4.10.4 Sampling Liquid Fuel. Samples of the fuel shall be taken so as to represent the fuel in its condition at the point of weighing. Sampling procedure outlined by PTC 3.1, Diesel and Burner Fuels, shall be followed.

4.10.4.1 Care must be exercised to ensure homogeneous fuel supply from storage throughout the test program. If this is not possible, fuel samples must be taken and tested each time the weigh tank is filled and correlated to fuel measurements.

4.10.5 Liquid Fuel Characteristics. It is necessary that the low heat value of the liquid fuel used for the test be determined by means of a standard form of bomb calorimeter (see ASTM D-2382).

4.10.5.1 Heat values and other pertinent characteristics shall be determined by a physical or chemical laboratory of recognized standing.

4.10.6 Reported characteristics, unless otherwise agreed upon between parties to the test, shall be limited to those upon which the specified performances are based. These may include:

4.10.6.1 Applicable to all liquid fuels: low-heat value, Btu per lb – ASTM D-2382; gravity API – ASTM D-287; sulfur – ASTM D-90 or ASTM D-129; water sediment – ASTM D-96; distillation temperatures in °F at initial; 5 percent; 10 percent;

and every 10 percent to 90 percent; 95 percent; end point; and percent recovery; residue and loss ASTM D-158 or ASTM D-86; and

4.10.6.2 Applicable to fuel oils (kerosene and heavier): ignition quality; octane number – ASTM D-613 or accepted equivalent method; carbon residue – ASTM D-189; pour point – ASTM D-97; ash – ASTM D-482; and viscosity Saybolt Universal or Furol – ASTM D-88; and

4.10.6.3 Applicable to gasoline and tractor fuels: ignition quality; octane number – ASTM D-357; or aviation fuel knock value – ASTM D-614; tetraethyl lead – ASTM D-526 or ASTM D-2509; gum – ASTM D-381; and vapor pressure – ASTM D-323.

4.11 Fuel Consumption, Gaseous Fuels

4.11.1 Measurements for gas consumption shall be made by means of calibrated rotary positive volumetric displacement meters, or sharp edge concentric orifice, long-radius nozzle, or Venturi meters as available and if rates of flow fall within the rated limits of the available meters.

4.11.1.1 Use of the rotary (Roots type) positive displacement meter for measurement of gas consumption is recommended for low pressure lines (below 125 psig or 861875 pascals gage) ranging from 1500 to 150,00 cu ft or 42.48 to 4248 cu meters displacement per hr. High pressure types are available for pressures up to 650 psi (or 4481750 pascals). The percentage correction to be added to the observed volume shall be determined from calibration curve provided with each meter. (Use these meters in the 25 percent to 100 percent flow range where the corrections are less than 1.0 percent.)

4.11.1.2 Gas consumption from flow measurements by means of nozzles, concentric orifices, or Venturi tubes can be determined to a maximum inaccuracy of 1.5 percent when testing within the proper Reynolds number. The technique and precautions for flow measurements as given in ASME Publication "Fluid Meters," Part II, shall be carried out in detail. Use of standardized nozzles or concentric orifice plates and their installation procedures will eliminate the need for special calibration at the time of the engine test.

4.11.2 Observations for Flow Measurement. For flow measurements the following precise observations are required (see summary below).

4.11.3 General Precautions for Flow Measurements. There are several independent factors that may introduce appreciable errors in the indicated volume. These are:

(a) Ratio of throat diameter to pipe diameter.
(b) Critical dimensions of metering elements.
(c) Condition of the meter flow surfaces.
(d) Ratio of downstream to upstream pressure.
(e) Location of the taps for determining pressure.
(f) Location and character of fittings in pipeline near the meter.
(g) On nozzle and Venturi meters, Reynolds number must exceed 150,000 to avoid excessive deviations.
(h) Steadiness of flow.
(i) Physical properties of the gas.
(j) Arrangement of manometers.
(k) Liquid entrained in gas stream.

SUMMARY OF OBSERVATIONS

		Orifice	Nozzle	Venturi	Positive Displacement
4.11.2.1	Pressure upstream	×	×	×	×
4.11.2.2	Temperature upstream	×	×	×	×
4.11.2.3	Pressure drop	×	×	×	×
4.11.2.4	Actual internal diameter of pipe upstream and downstream	×	×	×	
4.11.2.5	Complete dimensions of metering elements	×	×	×	

4.11.3.1 Procedures governing conditions of installation, method of use, and application of corrections relating to the above will be found in the references in ASME "Fluid Meters," Part II.

4.11.4 Sampling Gaseous Fuel. Samples of gas in the fuel line near the engine shall be taken so as to represent the gaseous fuel being burned. Sampling procedure prescribed by the Test Code for Gaseous Fuels, PTC 3.3, shall be followed, including the use of special bottles.

4.11.5 Gaseous Fuel Characteristics

4.11.5.1 Heating Value. The most accurate and recognized determination of the gas sample heating value will result from a mass spectrometer or gas chromatograph analysis. This analysis gives individual gas constituents in percentage volume on the unsaturated basis. When submitting a fuel gas sample for analysis specify either of the following:

4.11.5.1.1 Heating Value, Mass Spectrometer.

(a) Individual constituents determination – ASTM D-1137 and ASTM D-2650, coupled with

(b) Continuous calorimeter (HHV) – ASTM D-1826

4.11.5.1.2 Heating Value, Gas Chromatograph

(a) Individual constituent determination – ASTM D-1945, D-1946, and D-2163, coupled with

(b) Continuous calorimeter (HHV) – ASTM D-1826

4.11.5.1.3 The reason for specifying the use of the continuous monitoring calorimeter for both methods is to be assured that all gas components are measured. The HHV (saturated) recorded by the monitoring calorimeter must agree within 0.5 percent of the calculated HHV (saturated) from the composition analysis.

4.11.5.2 Specific Gravity. The determination of the flowing gas must be measured by the laboratory performing the gas composition tests (see ASTM D-1070).

4.11.5.2.1 The measured specific gravity must be compared to the calculated specific gravity, including the water vapor content, as outlined in ASTM D-1070. These values must agree within 0.5 percent.

4.11.5.3 Water Vapor Content. The water vapor content of the fuel should be obtained in accordance with ASTM D-1142. If fuel gas from a 600 psi (4137000 Pa), or higher pressure line is used, the water vapor content will be less than 0.1 percent and can be ignored.

4.11.6 Gaseous Fuels, Heating Value Calculations. Heat value of the gaseous fuel is to be calculated from the mass spectrometer or gas chromatograph analysis outlined in Par. 4.11.5.1.1 or 4.11.5.1.2 above. The low heat value (LHV) shall be the summation of the products obtained by multiplying the heat values of the individual constituent gases under standard conditions by the respective percent, by volume, of each constituent (see Par. 7.4.11.6). The object is to charge the engine with only the actual energy utilized. This is accomplished by correcting the fuel gas flow for water vapor content and using the LHV, *unsaturated*, of the gas.

4.12 Pressure Measurements

4.12.1 If pressure measurements directly influence the results of the test, the instrument used shall have a maximum inaccuracy of 0.5 percent. In general this will require use of calibrated Bourdon gages and/or deadweight gages for the higher pressures, and mercury or water manometers for the lower pressures. In cases where the measurement does not directly influence the results of the test, a maximum inaccuracy of 5.0 percent is permissible.

4.12.2 Bourdon gages should be selected so that the pressure to be read will be between one-quarter and three-quarters of the total scale. Manometers should have connecting piping of not less than one-quarter inch inside diameter to insure against capillarity in the piping. For gas or air pressures, it is preferable to arrange the connecting piping so that it will run continuously upward from source of pressure to manometers, without loops of any kind. Where liquid pressure is being measured, connecting piping should run continuously downward and the piping should be completely filled with the liquid being monitored.

4.12.2.1 See PTC 19.2 for further guidance and correction for liquid legs, etc.

4.12.3 Barometer and Mercury Columns. The atmospheric pressure to which mercury columns or manometers are to be referred may be determined by means of a suitable barometer. It is permissible to base atmospheric pressure conditions at site of test on a reading taken at the time of test from a local National Weather Service Station, but recognize that the readings they give are always corrected back to sea-level conditions. Barometers, other mercury columns, and manometers shall be corrected for temperature, meniscus (capillarity), gravity, and elevation differences where applicable. (See PTC 19.2 for additional details.)

4.13 Temperature Measurements

4.13.1 Where temperature measurements directly influence the results of the test, the potential combined temperature measurements shall be accurate enough to assure no more than 0.5 percent influence on the calculated results.

4.13.2 Select the type of temperature measuring instrument to best suit the application which will give the desired and necessary accuracies. These can include engraved-stem mercury thermometers, calibrated thermocouples and thermistors used in accordance with PTC 19.3

SECTION 5, COMPUTATION OF RESULTS

5.1 Computations for Primary Object Determinations: Power Output and Fuel Consumption

5.1.1 In computation of results of tests for the primary object, a point result for each test run is computed from the averaged or integrated values of observations made during that run, after applying instrument and other corrections as necessary and as prescribed in this Code. The reported net power output and fuel consumption for each test load and speed shall be the time-weighted average of the several corrected values.

5.2 Net Power Output, Direct

5.2.1 If the power output of an engine assembly (Par. 1.3) is measured with a dynamometer, the brake power output is computed (PTC 19.7) by:

$$\text{(FPS)}\ P_{mg} = \left(\frac{2\pi F_g n}{33{,}000}\right) \text{hp*}$$

$$\text{(SI)}\ P_{mg} = \left(\frac{2\pi F_g n}{60{,}000}\right) \text{kW**}$$

*One "hp" is equal to 33000 ft-lb/min
**One "kW" is equal to 60000 N-m/min

5.2.2 If separately driven accessories are included in the engine assembly, or if under provisions of Par. 1.3 power charges or credits must be made, corrections (ΣY_1) for the net power required by such additional accessories or auxiliaries shall be made.
Thus:

$$P_{mn} = (P_{mg} \pm \Sigma Y_1) \quad \text{hp} \quad \text{(FPS) or kW} \quad \text{(SI)}$$

5.3 Net Power Output, Indirect

5.3.1 Where power output is determined from electrical measurements of an engine-driven calibrated generator, the measured electrical power output at the generator terminals, expressed in kilowatts, will be the resultant sum of the electrical power output measurments plus cable or other losses (ΣY_3), in kilowatts, between the generator terminals and switchboard, if any, and less that portion of any excitation power, in kilowatts, that is separately supplied and less any power measured, in kilowatts, used for generator ventilation that is separately supplied, as detailed in Par. 4.8.1

5.3.2 In order that the foregoing shall give the net power output, electrical, in kilowatts, of an engine-driven calibrated generator, obtained in accordance with Par. 4.8, it is imperative that components of the actual engine-driven calibrated generator under test shall consist only of the engine assembly and generator apparatus as defined in Par. 1.3 of this Code. Corrections (ΣY_2) shall be made to adjust for power charges and credits introduced by separately driven auxiliaries or accessories as prescribed in Par. 1.3. This correction, evaluated in kilowatts, shall be made against the measured power output, electrical, before other prescribed corrections have been applied as above; then net power output is:

$$P_{en} = (P_{eg} \pm \Sigma Y_2 \pm \Sigma Y_3) \quad \text{kW}$$

5.3.3 If an alternating-current generator is used, the measured power output, electrical, Peg, may be calculated (PTC 19.6), upon agreement, by counting and timing the disc rotations of a polyphase watthour meter, and shall be corrected as indicated in the preceding paragraph for Y_2 and for Y_3. Then net power output is:

$$P_{en} = \left(\frac{3600 \times r_d \times PK_h}{1000 \times r_w} \pm \Sigma Y_2 \pm \Sigma Y_3\right) \text{kW}$$

5.4 Net Power Output, Other Indirect

5.4.1 If, as in the case of integral engine-compressors, the power output cannot be measured by calibrated generator or by dynamometer (in any of the forms approved in Par. 4.6.2), there should be mutual agreement as to how P_{mn} is to be determined.

5.5 Conversions Between Mechanical and Electrical Power Outputs

5.5.1 If it is desired to convert power output, electrical, to power output, mechanical, at the engine coupling, the net power output, electrical, is divided by the generator efficiency, η . In order to obtain FPS units it is also necessary to divide net output electrical by 0.746. (See Par. 7.5.5.1)

Depending upon the type of generator involved its losses will include some or all of the following:

(a) Stator I^2R loss
(b) Rotor I^2R loss
(c) Shunt field loss
(d) Shunt field rheostat loss
(e) Series winding I^2R loss
(f) Exciter losses
(g) Friction and windage
(h) Brush friction loss
(i) Brush contact loss
(j) Core loss
(k) Ventilating loss
(l) Stray load loss

5.5.1.1 In addition, cable losses must be calculated and included.

5.5.2 In accordance with Par. 5.5.1, the net power output, mechanical, in brake power at the engine coupling, is computed from the net power output, electrical (determined in Par. 5.3), and conversely the net power output electrical, in kilowatts at the generator terminals, is computed from the net power output, mechanical (determined in Par. 5.2), as follows:

Net Power Output, Mechanical or Electrical

(FPS) $$P_{mn} = \left(\frac{P_{en}}{0.746 \times \eta}\right) \text{hp}$$

(SI) $$P_{mn} = \left(\frac{P_{en}}{\eta}\right) \text{kW}$$

(FPS) $$P_{en} = (P_{mn} \times 0.746 \times \eta)\ \text{kW}$$

(SI) $$P_{en} = (P_{mn} \times \eta)\ \text{kW}$$

5.5.3 Total losses in the electric-generator as referred to in Par. 5.5.1 shall be determined from results obtained by tests made in accordance with PTC 19.6 on Electrical Measurements.

5.5.3.1 On the basis of these data, a curve of the total losses in the electric-generator against power output, electrical, shall be plotted and from this shall be read the values used to determine the correction to be applied to the specific test load. When electrical power measurements are made at the switchboard, cable losses to the generator terminals are determined separately and applied as in Par. 5.3.1

5.6 Net Specific Energy Consumption Rates

5.6.1 Net specific energy consumption rates are determined from measured fuel consumption rates (on a weight or volume basis), net power outputs and low heat value of the fuel used for test.

5.6.2 On a P_{mn} basis:

5.6.2.1 Where liquid fuel weight is measured

$$q_a = \left(W_2 \times \frac{3600^*}{r_{0_2}} \times \frac{Q_k}{P_{mn}}\right) \frac{\text{Btu}}{\text{hph}} \text{ (FPS) or } \frac{\text{J}}{\text{kWh}} \text{ (SI)}$$

*3600 sec/min.

5.6.2.2 Where gaseous fuel volume is measured:

$$q_a = \left(\frac{V_m}{Z} \frac{(p_m - p_w)}{p_s} \times \frac{T_s}{T_m} \times \frac{3600^*}{r_{0_3}} \times \frac{Q_g}{P_{mn}}\right) \frac{\text{Btu}}{\text{hph}} \text{ (FPS) or } \frac{\text{J}}{\text{kWh}} \text{ (SI)}$$

*3600 sec/min.

5.6.2.2.1 The value of p_w, water vapor pressure, will vary with T_m, and the percentage of saturation of the gas. For example, if T_m is 70°F or 21.1°C, then p_w will be 0.7392 in. Hg or 2503 pascals (as commonly expressed, or 0.491 × 0.7392 = 0.363 psi or 2503 pascals) for saturated gas; 0.3696 in. Hg or 3.3878 mm Hg (0.181 psi or 1251 pascals) for 50 percent saturation: and zero in the case of a dry gas. Tables showing p_w at various T_m's can be consulted. However, by mutual agreement p_w may be considered zero, as noted in Par. 4.11.5.3

5.6.2.2.2 If it is agreed that the measured volume V_m is to be corrected for non-ideal gas behavior (compressibility), it should be divided by the compressibility factor Z as noted in the formula.

5.6.2.2.3 If V_m is obtained in cu ft or m^3 per hr as is customary when using an orifice, the factor $\frac{3600}{r_{0_3}}$ is unity.

5.6.2.3 Where both weight and volume are measured (as in a gas-diesel engine),

$$\Sigma q_a = q_a \text{(computed per Par. 5.6.2.1)} + q_a \text{(computed per Par. 5.6.2.2)}$$

5.6.3 On a P_{en} basis:

5.6.3.1 Where liquid fuel weight is measured:

$$q_b = \left(W_2 \times \frac{3600^*}{r_{o_2}} \times \frac{Q_k}{P_{en}} \right) \frac{\text{Btu}}{\text{kWh}} \text{ (FPS) or } \frac{\text{J}}{\text{kWh}} \text{ (SI)}$$

*3600 sec/min.

5.6.3.2 Where gaseous fuel volume is measured:

$$q_b = \left(\frac{V_m}{Z} \times \frac{(p_m - p_w)}{p_s} \times \frac{T_s}{T_m} \times \frac{3600^*}{r_{o_3}} \times \frac{Q_g}{P_{en}} \right) \frac{\text{Btu}}{\text{kWh}} \text{ (FPS) or } \frac{\text{J}}{\text{kWh}} \text{ (SI)}$$

*3600 sec/min.

5.6.3.2.1 Also see Pars. 5.6.2.2.1, 5.6.2.2.2, and 5.6.2.2.3.

5.6.3.3 Where both weight and volume are measured (as in a gas-diesel engine),

$$\Sigma\, q_b = q_b \text{ (computed per Par. 5.6.3.1)} + q_b \text{ (computed per Par. 5.6.3.2).}$$

SECTION 6, REPORT OF TEST

6.1 General

6.1.1 The report of tests shall be prepared as a document in suitable form for the purpose of formally recording observed and computed data and for the conveying of sufficient supporting information to prove that all objects of any tests conducted in accordance with this Code have been attained.

6.1.2 The report of tests shall include essentially the following parts, in the order given:

I Title Page
II Index
III Conclusions
IV Test Methods
V Description Record
VI Observed and Computed Data
VII Test Performances – Curve Sheets and Summaries
VIII Record of Guarantees, Supplementary Agreements, and Contingent Operating Conditions
IX Supporting Data Incident to Test

The use of special forms is recommended to facilitate standardized presentation of test data. In any event the substance of these forms shall be incorporated in the report of tests as further detailed in the paragraphs which follow.

6.2 Part I Title Page

6.2.1 This part shall show the following information:

Item No.

6.2.1.1 Test Number . . . .
6.2.1.2 Date of test . . . .
6.2.1.3 Title of the report (sub-titles if needed) . . . .
6.2.1.4 Manufacturer's name and engine type and serial nember. . . . .
6.2.1.5 Location of test. . . . .
6.2.1.6 Test made for . . . .
6.2.1.7 Owner or purchaser represented by. .
6.2.1.8 Other parties to the test represented by. . . . .
6.2.1.9 Test directed by . . . .
6.2.1.10 Test approved by . . . .
6.3.1.11 Report made by . . . .
6.2.1.12 Address of reporter. . . . .
6.2.1.13 Date of report . . . .

6.3 Part II Index

6.3.1 This part should be included in every report and is particularly useful in test reports covering a number of different test objects which are reported as separate subdivisions.

6.4 Part III Conclusions

6.4.1 A part shall be included in which are formulated conclusions concerning attainment of the objectives of the tests and any recommendations or supplementary comments considered pertinent thereto. A statement shall be included indicating that all objectives have been determined in accordance with the ASME Test Code for Reciprocating Internal-Combustion Engines.

6.5 Part IV Test Methods

6.5.1 This part, depending upon the purpose and nature of the testing, shall include items selected from the following:

6.5.1.1 Explicit statement of:

6.5.1.1.1 Objectives of testing. . . . .
6.5.1.1.2 Instruments and apparatus employed and their calibration . . .
6.5.1.1.3 Methods of test procedure and measurement. . . . .
6.5.1.1.4 Methods of calculations . . . .
6.5.1.1.5 Results of testing. . . . .

6.5.1.2 Certification conformity:

6.5.1.2.1 Statement by the Test Director certifying that all measurements and determinations have been obtained in strict accordance with the provisions of this Code, with statement of exceptions and their import.

6.5.1.3 Details of methods of measurements employed for:

6.5.1.3.1 Primary objects
6.5.1.3.1.1 Net power output, direct . . .
6.5.1.3.1.2 Net power outputs, indirect .
6.5.1.3.1.3 Fuel Quantities . . . .
6.5.1.3.2 Additional objects (if any) . . . .
6.5.1.3.2.1 Other appropriate details. . . .

6.5.1.4 Additional information as follows:

6.5.1.4.1 Description of methods of measurement if different from the prescribed rules of Section 4 . . . . . .

6.5.1.4.2 Statement of departures from the rules of this Code, if any, that have been agreed to by parties to the test, including any extensions of permissible deviations from operating conditions of the test from those specified in this Code . . . .

6.5.1.4.3 Identification of calibration certificates and by whom made; description of calibration methods if not carried out by a recognized or national authority, and if methods other than those prescribed in Section 4 or in ASME "Supplements on Instruments and Apparatus," have been employed . . . . .

6.5.1.4.4 Supporting data including references to tables, charts, or curves employed in calculations of test results . . . .

6.5.1.4.5 Derivation of fuel characteristics and heat values and designation of laboratories utilized.

6.6 Part V Description Record

6.6.1 This part shall include a suitable description of the engine and its accessories and auxiliaries employed as part of the engine assembly (see Pars. 1.3.2 and 1.3.3) including information on make, type and serial number, construction and operating data, specifications and dimensions of importance, data on fuels, and other characteristics as detailed in this Code.

6.6.1.1 Engine, type and design features . . . . (including specifications and dimensions of importance)

6.6.1.2 Class of service or application . .

6.6.1.3 Auxiliaries and accessories driven by engine . . . .

6.6.1.4 Auxiliaries and accessories not driven by engine . . . . (include description and horsepower of driving equipment)

6.6.1.5 Generator efficiency, η . . . .

6.6.1.6 Liquid fuel employed . . . .

6.6.1.7 Gaseous fuel employed . . . .

6.7 Part VI Observed and Computed Data

6.7.1 This part shall include a record of observations and conditions pertinent to measuring power output and fuel consumption, and may include other items which are not actually required for calculating results. (Attention is directed to the requirements of Pars. 3.5.2, 3.5.2.2 and 3.5.2.4.)

6.7.2 Record of observations and computations for each test run and/or series of runs at each test point:

6.7.2.1 Test run number (for each run) . . . . . .

6.7.2.2 Time and rotative speed

6.7.2.2.1 Time, Start . . . .

6.7.2.2.2 Time, finish. . . . .

6.7.2.2.3 Duration of run, r_{0_1} (Item 6.7.2.2.2–Item 6.7.2.2.1) . . . .

6.7.2.2.4 Revolution counter at start . . . . .

6.7.2.2.5 Revolution counter at finish . . . .

6.7.2.2.6 Resultant total revolutions (Item 6.7.2.2.5 – Item 6.7.2.2.4)

6.7.2.2.7 Average or mean observed speed, n (Item 6.7.2.2.6 ÷ Item 6.7.2.2.3)

6.7.2.3 Power output, direct (mechanical)

6.7.2.3.1 Net weight on brake or dynamometer . . . .

6.7.2.3.2 Brake or dynamometer constant [Brake arm, R, ÷ 5252 (FPS) or 7040 (SI)]

6.7.2.3.3 Power output, mechanical, gross, P_{mg} (per Par. 5.2.1). . . . .

6.7.2.3.4 Corrections for auxiliaries and accessories, Y_1 . . . .

6.7.2.3.5 Power output, mechanical, net P_{mn} (per Par. 5.2.2) . . . .

6.7.2.3.6 Percent of rated power output, mechanical (Item 6.7.2.3.3 or 6.7.2.3.4) × 100 ÷ rated power output, mechanical, gross or net . . .

6.7.2.4 Power output, indirect (electrical)

6.7.2.4.1 Volts per phase . . . .

6.7.2.4.2 Amperes per phase . . . .

6.7.2.4.3 Power factor . . . .

6.7.2.4.4 Watthour meter constant, PK_h. . . .

6.7.2.4.5 Watthour meter disc turns, r_d . . . .

6.7.2.4.6 Duration of run, watthour meter, r_w . . . .

6.7.2.4.7 Power output, electrical, gross, P_{eg} . . . .

6.7.2.4.8 Corrections for auxiliaries and accessories, Y_2 . . . .

6.7.2.4.9 Corrections for cable losses, etc, Y_3 . . . .

6.7.2.4.10 Power output, electrical, net, P_{en}, (per Par. 5.3.3) . . . .

6.7.2.4.11 Percent of rated power output, electrical, (Item 6.7.2.4.7 or 6.7.2.4.10) × 100 ÷ rated power output, electrical, gross or net. . .

6.7.2.5 Liquid fuel consumption

6.7.2.5.1 Weight, start . . . .

6.7.2.5.2 Weight, finish. . . . .

6.7.2.5.3 Weight used, W_2 (Item 6.7.2.5.1 – Item 6.7.2.5.2) . . . .

6.7.2.5.4 Duration of run, fuel weighing, r_{0_2} . . . .

6.7.2.5.5 Liquid fuel energy consumption rate, q_a (per Par. 5.6.2.1) or q_b (Per Par. 5.6.3.1) . . . .

6.7.2.6 Gaseous fuel consumption

6.7.2.6.1 Meter reading, start . . . .

6.7.2.6.2 Meter reading, finish . . . .

6.7.2.6.3 Gas volume used, as measured, V_m (Item 6.7.2.6.2 – Item 6.7.2.6.1) . . . .

6.7.2.6.4 Duration of run, fuel measurement, r_{0_3} . . . .

6.7.2.6.5 Gaseous fuel energy consumption rate, q_a (per Par. 5.6.2.2) or q_b (per Par. 5.6.3.2) . . . .

6.7.2.7 Gas-diesel fuel consumption

6.7.2.7.1 Gas-diesel energy consumption rate, q_a (per Par. 5.6.2.3) or q_b (per Par. 5.6.3.3) . . . .

6.7.2.8 Pressures

6.7.2.8.1 Barometric . . . .

6.7.2.8.2 Gaseous fuel at meter inlet, p_m

6.7.2.8.3 Partial water pressure in gaseous fuel, p_w . . . .

6.7.2.8.4 Intake air manifold on engine. . . .

6.7.2.8.5 Injection gas before fuel nozzles

6.7.2.8.6 Lubricating oil, inlet at engine . .

6.7.2.8.7 Lubricating oil, inlet at cooler . .

6.7.2.8.8 Lubricating oil, outlet at cooler. .

6.7.2.8.9 Engine jacket coolant, inlet at engine . . . .

6.7.2.8.10 Engine jacket coolant, inlet at heat exchanger. . . . .

6.7.2.8.11 Engine jacket coolant, outlet at heat exchanger. . . . .

6.7.2.8.12 Exhaust back pressure . . . .

6.7.2.8.13 Combustion pressures, maximum for designated cylinders. . . . . . .

6.7.2.8.14 Compression pressures, engine hot, for designated cylinders. . . . . . .

6.7.2.9 Temperatures

6.7.2.9.1 Atmosphere, dry-bulb. . . . .

6.7.2.9.2 Atmosphere, wet-bulb. . . . .

6.7.2.9.3 Intake air, manifold on engine . . .

6.7.2.9.4 Gaseous fuel at meter on engine, T_m. . . . .

6.7.2.9.5 Exhaust at designated points . . .

6.7.2.9.6 Engine jacket coolant, inlet at engine . . . .

6.7.2.9.7 Engine jacket coolant, outlet at engine . . . .

6.7.2.9.8 Engine jacket coolant, temperature rise through engine (Item 6.7.2.9.7– Item 6.7.2.9.6) . . . .

6.7.2.9.9 Engine jacket coolant, inlet at heat exchanger. . . . .

6.7.2.9.10 Engine jacket coolant, outlet at heat exchanger . . . .

6.7.2.9.11 Lubricating oil, inlet at engine. . .

6.7.2.9.12 Lubricating oil, outlet at engine. .

6.7.2.9.13 Lubricating oil, sump . . . .

6.7.2.9.14 Lubricating oil, inlet at cooler . .

6.7.2.9.15 Lubricating oil, outlet at cooler. .

6.7.2.10 Characteristics of fuel, or fuels, used for Tests

6.7.2.10.1 Liquid Fuel

(a) High-heat value. . . . .

(b) Low-heat value, Q_k . . . .

(c) Cetane number . . . .

(d) Gravity . . . .

(e) Other data as required . . . .

6.7.2.10.2 Gaseous Fuel

(a) High-heat value, (Saturated). . . . .

(b) Low-heat value, Q_g (Unsaturated) . . . .

(c) Composition, constituent gases . . . . .

(d) Specified gas pressure, p_s . . . .

(e) Specified gas temperature, T_s . . . . . .

(f) Compressibility factor, Z . . . .

(g) Other data as required . . . .

6.8 Part VII Test Performance – Curve Sheets and Summaries

In this part, final results of tests shall be reported in the form of graphs and tabular summaries.

6.8.1 Primary Object Performance

6.8.1.1 Operation at constant speed and variable torque

6.8.1.1.1 Curves reporting the determined values at recorded speed of net specific energy-consumption rates, plotted against net power outputs, hp or kW

6.8.1.1.2 Tabular summary of net specific energy consumption rates determined from these curves, to correspond with specified or guaranteed power outputs.

6.8.1.2 Operation at variable speed and torque

6.8.1.2.1 Curves (or a family of curves) reporting point results of the individual tests for net power output, hp or kW, and the net specific energy-consumption rates, plotted against speed, rpm

6.8.1.2.2 Tabular summary of net power outputs and consumption rates determined from these curves, to correspond with specified or rated speeds.

6.9 Part VIII Record of Guarantees, Supplementary Agreements, and Contingent Operating Conditions

6.9.1 In this part of the report a statement shall be included of all agreements made in conformity with requirements of this Code. There must also be included a record of any other agreements, such as those covering predicted, guaranteed, or specified performances, operating conditions upon which the performances are based, and others per Pars. 3.2.1 and 3.2.2

6.10 Part IX Supporting Data Incident to Test

6.10.1 In this part shall be included pertinent material supplementing data presented elsewhere in the test report, which would be of assistance in making an independent verification of the reported results.

6.10.2 The supplementary material, depending upon the nature of the test covered by the report, may include:

(a) Detailed log sheets
(b) Various curves
(c) Sample calculations
(d) Blueprints, photographs, and bulky material.
(e) All other items called for in Par. 3.5, especially including Pars. 3.5.2.2, 3.5.2.4 and 3.5.3

SECTION 7, APPENDIX

7.0 General

7.0.1 The preceding Sections contain the details essential to the planning, execution and analysis of a Code test of a reciprocating internal-combustion engine. This Appendix provides additional information and commentary considered complementary to the basic guidance provided hereinbefore.

7.0.2 For ease in cross-reference, paragraphs in Section 7 are numbered the same as the paragraphs in preceding Sections to which they are most closely related, preceded by the number 7. For example, "7.1.1" refers to Par. 1.1 Sub-paragraphs within Section 7 not referring to a particular sub-paragraph in the main body are designated by a letter suffix: for example "7.1.1.i"

7.1.1 This Code is applicable to all types of reciprocating internal-combustion engines, for any purpose, where power output and fuel consumption rates are the primary objects of the tests. Thus, it is intended equally for small and large, stationary and mobile, or peaking and base-load engines. Generally, it is intended (and so written) for application to tests to verify performance.

7.1.1.i However, it is not designed for prototype or research and development testing, which frequently employs specialized objects, instrumentation and techniques not appropriate for inclusion herein.

7.1.1.ii It is also realized that for particular types of engines (e.g., automotive, aircraft, etc), particularly those mass produced for incorporation in other products, such as trucks, for which there customarily is not a specification by the ultimate user for the engine itself, there are other recognized codes or standards in common, effective use. While this Code is equally applicable, it behooves parties to the tests to be entirely clear as to the standards being used in specifying, and later testing, such engines.

7.1.2.3 In addition to testing for power output and fuel consumption there are potentially numerous optional tests desirable for determining other performance capabilities. These are not the province of this Code; such tests are too numerous, too seldom needed, and frequently too unproven to justify inclusion in this Code.

7.1.2.3.i Such tests might be concerned with:

(a) Combustion pressures
(b) Cooling performance
(c) Lubrication performance
(d) Critical speeds
(e) Governing
(f) Cyclic irregularity
(g) Exhaust gas analysis, back pressure, etc.
(h) Engine reversal
(i) Starting requirements

7.1.2.3.ii Various codes and standards exist for some of these tests, such as PTC 26 on Speed Governing, and should be used. Since the state of the art is changing rapidly in respect to some, the techniques and instrumentation must be developed specifically therefor and be subject to special agreement by the parties involved.

7.1.3.3 Preferably, the engine assembly to be tested shall be the engine and that assemblage of auxiliaries and systems to be charged or credited to the measured power output of the engine in determining the net power output and the energy input thereto as is stipulated in the pertinent specifications, and is termed the "Specified Engine Assembly." (All such auxiliaries and systems shall be itemized on the test records.) Engine practice varies widely with regard to attached and independently driven auxiliaries. Some engines, particularly the larger ones, have no attached auxiliaries; consequently, the user, in comparing different engines, should carefully evaluate all ratings, performance parameters, and fuel consumption rates when the attached auxiliary equipment varies, since such variation affects the amount of auxiliary power which must be provided, as well as the overall rate of fuel consumption.

7.1.3.3.i It was in recognition of this considerable variance between customary practices (especially between "large" and "small" engines) that two standard Engine Assemblies were devised. In the absence of specifications stipulating the auxiliaries to be included in the test, a

Code Engine Assembly will be the recognized basis for comparison between engines.

7.1.3.3.ii The rating of an engine shall be the power that the engine will deliver continuously at its coupling when in good operating order, and under conditions as specified. Exhaust back pressure, and pressure drop through intake air system, should not exceed limits specified.

7.1.3.3.iii Because of the different ways in which engines may be equipped with respect to their attached or independently driven essential apparatus, it is necessary to consider the parasitic load of such power consuming apparatus in determining net power for comparative purposes. The parasitic load of the power consuming equipment, only, is to be included as a basis for establishing net power and fuel consumption unless other conditions are invoked by the specifications.

7.3.2.1.(d) With few exceptions, the engine manufacturers' shops are the only facilities that are adequately equipped with calibrated test equipment; therefore, it is recommended, unless otherwise specified or agreed, the performance tests be conducted at the works of the engine manufacturer.

7.3.4.3 Fuel (or energy) consumption rates are to be expressed in terms of Btu per hp-hr (FPS) or Joules per kWh (SI). In so doing it is unnecessary to refer to any standard fuel weight or volume basis (liquid or gaseous fuels, respectively) for the fuels, hence no standards are specified herein. However, it is necessary to correlate the measured quantities with the basis used by the laboratory in establishing the energy content of the fuel.

7.3.4.3.i Gas volume measurements referred to standard conditions adopted by ASTM and the gas industry are recognized under terms of this Code, provided the basic conditions for referring measurements are stated in the test report.

7.3.4.3.ii In cases where gases being measured are partially or completely saturated, corrections shall be applied to gas-volume measurements to adjust for actual water-vapor content in gas consumed.

7.3.4.3.iii The heating value of fuels containing hydrogen includes some energy not available for conversion into work in any internal-combustion engine. Hence, under this Code, fuel and heat consumption rates shall be determined on basis of low heat values of the fuels, thereby eliminating the heat of vaporization of the water formed by the burning of the hydrogen in the fuel. The difference between the high and low heat values of commercially available petroleum fuels used in liquid-fuel engines is a fairly constant percentage. For gaseous fuels the percentage difference between the high and low heat values may range from zero to more than 15 percent.

7.3.4.3.iv Various terms included in this Code relative to gaseous fuels and heat values are amplified as follows:

(a) High (Gross) Heat Value. The total energy released from a unit of fuel as the products of combustion are brought to the same state of pressure and temperature as the fuel-air mixture.

(b) Low (Net) Heat Value. The high heat value of a fuel less the latent heat of vaporization of the water vapor present in the exhaust gas at its exit partial pressure (ie, the HHV less the unusable products of burning the contained hydrogen).

(c) Dry Gas. A mixture of hydrocarbon gases with relatively low percentages of propane and heavier hydrocarbons components.

(d) Wet Gas. A mixture of hydrocarbon gases with relatively high percentages of propane and heavier components.

(e) Saturated Gas. A hydrocarbon mixture saturated with water vapor.

(f) Unsaturated Gas. A hydrocarbon mixture with negligible water vapor present.

(g) Compressibility (Z). That characteristic of a gas which measures its deviation from ideal gas behavior expressed as $Z = PV/RT$.

(h) Supercompressibility Factor. An expression of F, equal to $\frac{1}{(Z)^{1/2}}$. It is used to simplify orifice flow calculation.

7.3.4.3.v Selecting a laboratory for analyzing the fuels in accordance with this Code is critical to its effectiveness. Although there are many chemical and physical laboratories which profess a capability to analyze fuel heating values, relatively few are actually capable of performing the analyses specified in Pars. 4.4.1.3, 4.10.5, 4.10.6, 4.11.5 and 4.11.6. Hence, selection of analysis method and laboratory must be correlated and assurance obtained that the selected laboratory is equipped, staffed, capable and experienced in such procedures.

7.4.4.1.1.3 There are circumstances where engine-driven mechanisms realistically prevent direct or indirect determination of power output in accordance with Pars. 4.4.1.1.1 and 4.4.1.1.2. Such instances include commercial generators, certain compressor drives, propeller drives, etc.

7.4.4.1.1.3.i In field testing one is quite often confronted with a commercial generator (normally uncalibrated) for measuring engine power output. Though inaccuracy is usually closer than ±5.0 percent, it is not normally so guaranteed. Hence, results must be weighed accordingly.

7.4.4.1.1.3.ii For engine driven compressor units, the horsepower generally must be measured from compressor cylinder indicator cards. It is recognized that piston ring and rod packing friction reduces efficiency. Efficiency values should be obtained from the compressor manufacturer (see AGA X20170). (Also see PTC 19.8.) Maximum inaccuracy: balanced pressure indicator, ±3.0 percent; electronic indicator, ±5.0 percent. (See also Par. 7.4.9)

7.4.4.1.1.3.iii Similar circumstances and precautions pertain to pump drives, propeller drives, gear drives, etc. Attention is directed to PTC 19.7 for pertinent methods of power measurement.

7.4.8.2 In cases where alternating-current generating sets are operated in parallel with other such sets, the power factor for the engine generator set under test shall, if possible, be adjusted by regulating excitation of other sets and of the set being tested until the power factor of the set under test is at the value stated in the specifications, or as agreed upon by the parties to the test, including values for adjusting results for different power factor.

7.4.9 The net engine power input to an engine-driven compressor (with engine assembly as specified in Par. 1.3) shall be determined from compressor-cylinder indicator diagrams (expressed in indicated mechanical power) with adjustment made to compensate for compressor mechanical efficiency. The compressor mechanical efficiency must be agreed upon by parties to the test prior to testing. (See Par. 7.4.4.1.1.3.ii)

7.4.9.i The power output of an engine, when measured by compressor-cylinder indicator diagrams, shall be determined by use of either a balanced-pressure indicating system or an electronic indicating system, preferably one which employs digital electronics. (See PTC 19.8)

7.4.9.ii Although the intrinsic accuracy of both indicating systems can be high, usually the accuracy resulting under the conditions of use will control overall accuracy. For example, a 1-degree top center displacement may result in an error of from 2 to 5 percent in the measurement of the indicated power of the machine. Cyclic irregularity due to either speed variations or pressure pulsations transmitted from adjoining compressor units operating at different speeds can affect interpretation of the mean pressure path of the diagram. Further information concerning indicating instruments and practice is given in PTC 19.8 – "Measurement of Indicated Power."

7.4.11.6 For purposes of evaluating heating values of fuel constituents Table 2 is included. It 'is provided by the Natural Gas Processors Suppliers Association, Tulsa, Oklahoma.

7.5.5.1 Where an uncalibrated generator is used for power measurement it generally is necessary to rely on the generator efficiency guaranteed by the generator manufacturer as the basis for converting net electrical power output to net engine power output. In addition, cable losses must be calculated and included.

TABLE 2

Table 2 – Physical Constants of Hydrocarbons [P](1)

No.	Compound	Formula	Molecular Weight	Boiling Point °F., 14.696 psi., abs.	Vapor Pressure 100°F., psi., abs.	Freezing Point, °F., 14.696 psi., abs.	Critical Constants: Pressure, psi., abs.	Critical Constants: Temperature, °F.	Critical Constants: Volume, cu. ft. per lb.	Density of Liquid; 60°F., 14.696 psi., abs.: Specific Gravity 60°F./60°F.[a,b]	lb. per gal.[a] (Wt. in Vacuum)	lb. per gal.[a,c] (Wt. in Air)	Gal/Lb. Mol[a]	Temperature Coefficient of Density[a]
1	Methane	CH_4	16.042	−258.68	—	−296.46[d]	673.1	−115.78	0.0991	0.3[i]	2.5[i]	2.5[i]	6.4[i]	—
2	Ethane	C_2H_6	30.068	−127.53	—	−297.89[d]	709.8	+90.32	0.0788	0.3771[h]	3.14[h]	3.13[h]	9.56[h]	—
3	Propane	C_3H_8	44.094	−43.73	190	−305.84[d]	617.4	206.26	0.0728	0.5077[h]	4.233[h]	4.220[h]	10.42[h]	0.00152[h]
4	n-Butane	C_4H_{10}	58.120	+31.10	51.6	−217.03	550.7	305.62	0.0702	0.5844[h]	4.872[h]	4.865[h]	11.93[h]	0.00117[h]
5	2-Methylpropane (isobutane)	C_4H_{10}	58.120	+10.89	72.2	−255.28	529.1	274.96	0.0724	0.5631[h]	4.695[h]	4.686[h]	12.38[h]	0.00119[h]
6	n-Pentane	C_5H_{12}	72.146	96.93	15.570	−201.50	489.5	385.5	0.0690	0.6312	5.262	5.253	13.71	0.00087
7	2-Methylbutane (isopentane)	C_5H_{12}	72.146	82.13	20.44	−255.82	483.	369.0	0.0685	0.6248	5.209	5.199	13.85	0.00090
8	2,2-Dimethylpropane (neopentane)	C_5H_{12}	72.146	49.10	35.9	+2.21	464.0	321.08	0.0674	0.5967[h]	4.975[h]	4.965[h]	14.50[h]	0.00104[h]
9	n-Hexane	C_6H_{14}	86.172	155.73	4.956	−139.63	440.0	454.1	0.0685	0.6640	5.536	5.526	15.57	0.00075
10	2-Methylpentane	C_6H_{14}	86.172	140.49	6.767	−244.61	440.1	435.7	0.0681	0.6579	5.485	5.476	15.71	0.00078
11	3-Methylpentane	C_6H_{14}	86.172	145.91	6.098	—	453.1	448.2	0.0681	0.6690	5.578	5.568	15.45	0.00075
12	2,2-Dimethylbutane (neohexane)	C_6H_{14}	86.172	121.53	9.856	−147.77	450.7	420.1	0.0667	0.6540	5.453	5.443	15.80	0.00078
13	2,3-Dimethylbutane	C_6H_{14}	86.172	136.38	7.404	−199.37	455.4	440.2	0.0665	0.6664	5.556	5.546	15.51	0.00075
14	n-Heptane	C_7H_{16}	100.198	209.17	1.620	−131.10	396.8	512.62	0.0682	0.6882	5.738	5.728	17.46	0.00069
15	2-Methylhexane	C_7H_{16}	100.198	194.09	2.271	−180.90	400.	495.	0.0685	0.6830	5.694	5.685	17.60	0.00068
16	3-Methylhexane	C_7H_{16}	100.198	197.33	2.130	—	413.	504.4	0.0668	0.6915	5.765	5.758	17.38	0.00069
17	3-Ethylpentane	C_7H_{16}	100.198	200.26	2.012	−181.49	420.	513.8	0.0665	0.7026	5.858	5.849	17.10	0.00070
18	2,2-Dimethylpentane	C_7H_{16}	100.198	174.55	3.492	−190.86	417.	477.9	0.0646	0.6783	5.655	5.645	17.72	0.00072
19	2,4-Dimethylpentane	C_7H_{16}	100.198	176.90	3.292	−182.64	403.	476.9	0.0671	0.6772	5.646	5.637	17.75	0.00072
20	3,3-Dimethylpentane	C_7H_{16}	100.198	186.92	2.773	−210.03	440.	505.0	(0.067)	0.6977	5.817	5.807	17.23	0.00065
21	2,2,3-Trimethylbutane (triptane)	C_7H_{16}	100.198	177.59	3.374	−12.84	437.2	497.0	0.0631	0.6945	5.790	5.782	17.31	0.00069
22	n-Octane	C_8H_{18}	114.224	258.20	0.537	−70.23	362.1	563.7	0.0682	0.7068	5.893	5.883	19.38	0.00062
23	2,5-Dimethylhexane (diisobutyl)	C_8H_{18}	114.224	228.39	1.101	−132.16	362.	530.	0.0676	0.6980	5.819	5.810	19.63	0.00065
24	2,2,4-Trimethylpentane ("isooctane")	C_8H_{18}	114.224	210.63	1.708	−161.28	374.7	520.1	0.0676	0.6963	5.805	5.795	19.68	0.00065
25	n-Nonane	C_9H_{20}	128.250	303.44	0.179	−64.33	332.	610.5	0.0679	0.7217	6.017	6.008	21.31	0.00063
26	n-Decane	$C_{10}H_{22}$	142.276	345.42	0.073	−21.39	304.	651.9	0.0679	0.7341	6.120	6.112	23.25	0.00055
27	Cyclopentane	C_5H_{10}	70.130	120.67	9.914	−136.96	654.7	461.48	0.0593	0.7505	6.257	6.247	11.21	0.00070
28	Methylcyclopentane	C_6H_{12}	84.156	161.26	4.503	−224.42	549.0	499.30	0.0607	0.7535	6.282	6.274	13.40	0.00071
29	Cyclohexane	C_6H_{12}	84.156	177.33	3.264	+43.80	591.5(19)	535.6(19)	0.0587(17)	0.7834	6.531	6.522	12.89	0.00068
30	Methylcyclohexane	C_7H_{14}	98.182	213.68	1.609	−195.87	504.4	570.2	0.0562	0.7740	6.453	6.443	15.21	0.00063
31	Ethene (ethylene)	C_2H_4	28.052	−154.68	—	−272.47[d]	742.1	49.82	0.0706	0.35(16)	—	—	—	—
32	Propene	C_3H_6	42.078	−53.86	226.4	−301.45[d]	667.	197.4	0.0689	0.5220[h]	4.352[h]	4.343[h]	9.67[h]	0.00189[h]
33	1-Butene	C_4H_8	56.104	+20.73	63.05	−301.63[d]	583.	295.6	0.0689	0.6013[h]	5.013[h]	5.004[h]	11.19[h]	0.00116[h]
34	cis-2-Butene	C_4H_8	56.104	38.70	45.54	−218.04	600.	324.3	0.0503	0.6271[h]	5.228[h]	5.219[h]	10.73[h]	0.00098[h]
35	trans-2-Butene	C_4H_8	56.104	33.58	49.80	−157.99	600.	311.9	0.0503	0.6100[h]	5.086[h]	5.076[h]	11.03[h]	0.00107[h]
36	2-Methylpropene (isobutene)	C_4H_8	56.104	19.58	63.40	−220.63	579.8	292.5	0.0513	0.6004[h]	5.006[h]	4.996[h]	11.21[h]	0.00120[h]
37	1-Pentene	C_5H_{10}	70.130	85.94	19.12	−265.40	586.	376.9	(0.0672)	0.6457	5.383	5.374	13.03	0.00089
38	1,2-Butadiene	C_4H_6	54.088	51.53	(20)	−213.14	(653)	(339)	(0.0649)	0.658[h]	5.486[h]	5.47[h]	9.86[h]	0.00098[h]
39	1,3-Butadiene	C_4H_6	54.088	24.06	(60)	−164.05	628.	306.	(0.0654)	0.6272	5.229[h]	5.220[h]	10.34[h]	0.00113[h]
40	2-Methyl-1,3-butadiene (isoprene)	C_5H_8	68.114	93.32	16.672	−230.71	(558)	(412)	(0.0650)	.6861	5.720	5.711	11.91	0.00086
41	Ethyne (acetylene)	C_2H_2	26.036	−119[e]	—	−114[d]	905.	97.4	0.0695	0.6150[k]	—	—	—	—
42	Benzene	C_6H_6	78.108	176.18	3.224	+41.96	714.	552.0	0.0535	0.8845	7.374	7.365	10.59	0.00066
43	Toluene	C_7H_8	92.134	231.12	1.032	−138.98	590.	605.5	0.0564	0.8719	7.269	7.260	12.67	0.00060
44	Ethylbenzene	C_8H_{10}	106.160	277.13	0.371	−138.96	540.	651.2	0.0556	0.8717	7.268	7.259	14.61	0.00054
45	1,2-Dimethylbenzene (o-xylene)	C_8H_{10}	106.160	291.94	0.264	−13.33	530.	674.8	0.0584	0.8848	7.377	7.367	14.39	0.00055
46	1,3-Dimethylbenzene (m-xylene)	C_8H_{10}	106.160	282.39	0.326	−54.17	510.	649.9	0.0584	0.8687	7.243	7.234	14.66	0.00054
47	1,4-Dimethylbenzene (p-xylene)	C_8H_{10}	106.160	281.03	0.324	+55.87	500.	649.4	0.0556	0.8657	7.218	7.209	14.71	0.00054
48	Styrene (Phenyl Ethylene)	C_8H_8	104.144	293.25	(0.24)	−23.13	580.	706.0	0.0541	0.9111	7.596	7.586	13.71	0.00057
49	Isopropylbenzene (cumene)	C_9H_{12}	120.186	306.31	0.188	−140.86	460.	676.2	0.0591	0.8663	7.223	7.213	16.64	0.00054
50	Methyl Alcohol	CH_4O	32.042	148.1(2)	4.63(22)	−143.82(22)	1174.2(21)	462.97(21)	0.0589(21)	0.796(3)	6.64	6.63	4.83	—
51	Ethyl Alcohol	C_2H_6O	46.069	172.92(22)	2.3(7)	−173.4(22)	925.3(21)	469.58(21)	0.0580(21)	0.794(3)	6.62	6.61	6.96	—
52	Carbon Monoxide	CO	28.010	−313.6(2)	–	−340.6(2)	507.(17)	−220.(17)	0.0532(17)	0.801[m](8)	—	—	—	—
53	Carbon Dioxide	CO_2	44.010	−109.3(2)	–	–	1071.(17)	87.9(23)	0.0342(23)	0.827[h](6)	6.90[h]	6.89[h]	6.38[h]	—
54	Hydrogen Sulfide	H_2S	34.076	−76.6(24)	394.0(6)	−117.2(7)	1306.(17)	212.7(17)	0.0459(24)	0.79[h](6)	6.59[h]	6.58[h]	5.17[h]	—
55	Sulfur Dioxide	SO_2	64.060	+14.0(7)	88.(7)	−103.9(7)	1145.(24)	315.5(17)	0.0306(24)	1.397[h](14)	11.65[h]	11.63[h]	5.50[h]	—
56	Ammonia	NH_3	17.032	−28.2(24)	212.(7)	−107.9(2)	1636.(17)	270.3(24)	0.0681(17)	0.6173(11)	5.15	5.14	3.31	—
57	Air	N_2O_2	28.966	−317.6(2)	—	—	547.(2)	−221.3(2)	0.0517(3)	0.856[m](8)	—	—	—	—
58	Hydrogen	H_2	2.016	−423.0(24)	—	−434.8(24)	188.1(17)	−399.8(17)	0.5167(24)	0.07[m](3)	—	—	—	—
59	Oxygen	O_2	32.000	−297.4(2)	—	−361.8(24)	736.9(24)	−181.1(17)	0.0382(24)	1.14[m](3)	—	—	—	—
60	Nitrogen	N_2	28.016	−320.4(2)	—	−346.0(24)	493.0(24)	−232.4(24)	0.0514(17)	0.808[m](3)	—	—	—	—
61	Chlorine	Cl_2	70.914	−29.3(24)	158.(7)	−149.8(24)	1118.4(24)	291.(17)	0.0281(17)	1.414(14)	11.79	11.78	6.02	—
62	Water	H_2O	18.016	+212.0	0.9492(12)	32.0	3208.(17)	705.6(17)	0.0500(17)	1.000	8.337	8.328	2.16	—
63	Hydrogen Chloride	HCl	36.465	−121(16)	925(7)	−173.6(16)	1198.(17)	124.5(17)	0.0208(17)	0.8558(14)	7.135	7.127	5.11	0.003346[n]

Table 2 – Physical Constants of Hydrocarbons P(1), (Cont'd)

Pitzer Accentric Factor (18)	Compressibility Factor of real gas, Z 14,696 psia, 60° F	Gas Density, 60 F, 14.696 psi., abs. Ideal Gas*: Specific Gravity* Air = 1	Gas Density: cu. ft. Gas per lb.*	Gas Density: cu. ft. Gas per gal. Liquid*	Specific Heat 60 F., 14.696 psi., abs. Cp Btu./lb/°F: Ideal Gas	Specific Heat Cp: Liquid	Calorific Value, 60 F* Net: Btu. per cu. ft. Ideal Gas, 14,696 psi., abs. (20)*	Calorific Value Gross: Btu. per cu. ft. Ideal Gas, 14,696 psi., abs. (20)*	Gross: Btu. per lb. Liquid (Wt. in Vacuum)*	Gross: Btu per gal. Liquid*	Heat of Vaporization, 14.696 psi., abs. at Boiling Point, Btu. per lb.	Refractive Index*, nD 68° F.	Air Required for Combustion* Ideal Gas cu. ft. per cu. ft.	Flammability Limits, Vol. % in Air Mixture: Lower	Flammability Limits: Higher	A.S.T.M. Octane Number: Motor Method D-357	A.S.T.M. Octane Number: Research Method D-908	No.
0.013	0.9981	0.5538	23.66	59.[j]	0.5271		909	1010	—	—	219.2	—	9.55	5.0	15.0	—	—	1
0.105	0.9916	1.038	12.62	39.7[h]	0.4097	0.926[h]	1618	1769	—	—	210.4	—	16.71	2.9	13.0	+0.05[f]	+1.6[f,j]	2
0.152	0.9820	1.522	8.606	36.43[h]	0.3885	0.592[h]	2316	2517	21.49[g]	—	183.1	—	23.87	2.1	9.5	97.1	+1.8[f,j]	3
0.201	0.9667	2.006	6.529	31.81[h]	0.3908	0.564[h]	3011	3262	21,136	102.980	165.7	1.3326[h]	31.03	1.8	8.4	89.6[j]	93.8[j]	4
0.192	0.9699	2.006	6.529	30.66[h]	0.3872	0.570[h]	3001	3253	21,086	98.990	157.5	—	31.03	1.8	8.4	97.6	+0.10[f,j]	5
0.252	0.9435	2.491	5.260	27.68	0.3883	0.542	3707	4009	20,926	110.120	153.6	1.35748	38.19	1.4	8.3	62.6[j]	61.7[j]	6
0.206	0.9482	2.491	5.260	27.40	0.3827	0.5353	3698	4000	20,887	106.800	147.1	1.35373	38.19	1.4	(8.3)	90.3	92.3	7
0.195	(0.95)	2.491	5.260	26.17[h]	0.3914	0.554	3685	3987	20,836	103.650	135.6	1.342[h]	38.19	1.4	(8.3)	80.2	85.5	8
0.290	—	2.975	4.404	24.38	0.3864	0.5333	4403	4756	20,784	115.060	144.0	1.37486	45.35	1.2	7.7	26.0	24.8	9
—	—	2.975	4.404	24.16	—	0.5264	4395	4747	20,756	113.850	138.7	1.37145	45.35	1.2	(7.7)	73.5	73.4	10
—	—	2.975	4.404	24.56	—	0.507	4398	4751	20,768	115.840	140.1	1.37652	45.35	(1.2)	(7.7)	74.3	74.5	11
—	—	2.975	4.404	24.01	—	0.5165	4382	4735	20,711	112.930	131.2	1.36876	45.35	(1.2)	(7.7)	93.4	91.8	12
—	—	2.975	4.404	24.47	—	0.5127	4391	4744	20,743	115.250	136.1	1.37495	45.35	(1.2)	(7.7)	94.3	+0.3[f]	13
0.352	—	3.459	3.787	21.73	0.3853	0.5276	5100	5502	20,681	118.660	136.0	1.38764	52.51	1.0	7.0	0.0	0.0	14
—	—	3.459	3.787	21.57	—	0.522	5092	5495	20,658	117.630	131.6	1.38485	52.51	(1.0)	(7.0)	46.4	42.4	15
—	—	3.459	3.787	21.83	—	0.511	5095	5497	20,668	119.160	132.1	1.38864	52.51	(1.0)	(7.0)	55.8	52.0	16
—	—	3.459	3.787	22.19	—	0.506	5098	5500	20,679	121.130	132.8	1.39339	52.51	(1.0)	(7.0)	69.3	65.0	17
—	—	3.459	3.787	21.42	—	0.517	5079	5482	20,620	116.610	125.1	1.38215	52.51	(1.0)	(7.0)	95.6	92.8	18
—	—	3.459	3.787	21.38	—	0.522	5084	5486	20,636	116.510	126.6	1.38145	52.51	(1.0)	(7.0)	83.8	83.1	19
—	—	3.459	3.787	22.03	—	.502	5084	5487	20,638	120.050	127.2	1.39092	52.51	(1.0)	(7.0)	86.6	80.8	20
—	—	3.459	3.787	21.93	—	.498	5081	5483	20,627	119.430	124.2	1.38944	52.51	(1.0)	(7.0)	+0.1[f]	+1.8[f]	21
—	—	3.943	3.322	19.58	0.3845	0.52.30	5796	6249	20,604	121.420	129.5	1.39743	59.67	0.96	—	—	—	22
—	—	3.943	3.322	19.33	—	0.5114	5780	6233	20.564	119.670	122.8	1.39246	59.67	(0.98)	—	55.7	55.2	23
—	—	3.943	3.322	19.29	—	0.4892	5778	6231	20.569	119.390	116.7	1.39145	59.67	1.0	—	*100*	*100*	24
—	—	4.428	2.959	17.80	—	0.5220	6493	6996	20,543	123.610	126.7	1.40542	66.83	0.87[a]	2.9	—	—	25
—	—	4.912	2.667	16.32	—	0.5207	7189	7743	20.495	125.440	118.7	1.41189	73.99	0.78[a]	2.6	—	—	26
0.193	—	2.421	5.411	33.86	—	0.4216	3512	3763	20.187	126.310	167.3	1.40645	35.80	(1.4)	—	84.9[j]	+0.1[f]	27
0.234	—	2.905	4.509	28.33	—	0.4407	4198	4500	20.129	126.450	147.8	1.40970	42.96	(1.2)	8.35	80.0	91.3	28
0.186	—	2.905	4.509	29.45	—	0.4332	4180	4482	20.038	130.880	153.7	1.42623	42.96	1.3	7.8	77.2	83.0	29
—	—	3.390	3.865	24.94	—	0.4397	4864	5216	20.003	129.080	138.9	1.42312	50.12	1.2	—	71.1	74.8	30
—	0.9940	0.9684	13.53	—	0.3622	—	1499	1599	—	—	207.6	—	14.32	2.7	34.0	75.6	+0.03[f]	31
0.143	0.9839	1.453	9.019	39.25[h]	0.3541	—	2183	2334	—	—	188.2	—	21.48	2.0	10.0	84.9	+0.2[f]	32
0.203	0.9694	1.937	6.764	33.91[h]	0.3548	—	2879	3081	20.679	103.670	167.9	—	28.64	1.6	9.3	80.8[j]	97.4	33
0.273	0.9653(15)	1.937	6.764	35.36[h]	0.3269	—	2872	3073	20.613	107.770	178.9	—	28.64	(1.6)	—	83.5	100.	34
0.234	0.9654(15)	1.937	6.764	34.40[h]	0.3654	—	2868	3068	20.584	104.680	174.4	—	28.64	(1.6)	—	—	—	35
0.201	0.9687(15)	1.937	6.764	33.86[h]	0.3701	—	2860	3061	20.548	102.860	169.5	—	28.64	(1.6)	—	—	—	36
—	(0.95)	2.421	5.411	29.13	—	0.5196	3576	3827	20.550	110.630	154.5	1.37148	35.80	(1.4)	8.7	77.1	90.9	37
—	(0.97)	1.867	7.016	38.49[h]	0.3458	0.5408	2789	2940	20.461	—	(181)	—	26.25	(2.0)	(12)	—	—	38
—	0.975	1.867	7.016	36.69[h]	0.3412	0.5079	2730	2881	20.039	104.790	(174)	—	26.25	2.0	11.5	—	—	39
—	(0.96)	2.352	5.571	31.87	0.357	0.5245	3411	3612	19.955	114.150	(153)	1.42194	33.41	(1.5)	—	81.0	99.1	40
0.186	0.9925	0.8988	14.58	—	0.3966	—	1422	1473	—	—	—	—	11.93	2.5	80	—	—	41
0.215	0.929(15)	2.697	4.859	35.83	—	0.4098	3591	3742	17.991	132.670	169.3	1.50112	35.80	1.3[g]	7.9[g]	+2.8[f]	—	42
0.252	0.903(21)	3.181	4.119	29.94	—	0.4017	4273	4475	18.251	132.670	156.2	1.49693	42.96	1.2[g]	7.1[g]	+0.3[f]	+5.8[f]	43
—	—	3.665	3.575	25.98	—	0.4114	4970	5222	18.494	134.110	145.7	1.49588	50.12	0.99[g]	6.7[g]	+97.9	+0.8[f]	44
—	—	3.665	3.575	26.37	—	0.4418	4958	5210	18.445	136.070	149.1	1.50545	50.12	1.1[g]	6.4[g]	100.	—	45
—	—	3.665	3.575	25.89	—	0.4045	4957	5208	18.441	133.560	147.4	1.49722	50.12	1.1[g]	6.4[g]	+2.8[f]	+4.0[f]	46
—	—	3.665	3.575	25.80	—	0.4083	4957	5209	18.445	133.130	146.1	1.49582	50.12	1.1[g]	6.6[g]	+1.2[f]	+3.4[f]	47
—	—	3.595	3.644	27.68	—	0.4122	4830	5031	18.150	137.870	(151)	1.54682	47.73	1.1	6.1	+0.2[f]	>+3[f]	48
—	—	4.149	3.158	22.81	—	(0.41)	5661	5963	18.653	134.710	134.3	1.49145	57.28	0.88[g]	6.5[g]	99.3	+2.1[f]	49
—	—	1.106	11.84	78.6	—	0.594(7)	—	—	9,760(16)	64.810	473(2)	1.3288(8)	7.15(7)	6.72(5)	36.50	—	—	50
—	—	1.590	8.237	54.5	—	0.562(7)	—	—	12,780(16)	84.600	367(2)	1.3614(8)	14.30(7)	3.28(5)	18.95	—	—	51
0.041	0.9995(15)	0.9670	13.55	—	0.2484(13)	—	—	321[r](13)	—	—	92.7(14)	—	2.38(7)	12.50(5)	74.20	—	—	52
0.225	0.9943(15)	1.519	8.623	59.4[h]	0.1991(13)	—	—	—	—	—	238.2[n](14)	—	—	—	—	—	—	53
0.100	0.9903(15)	1.176	11.14	73.4[h]	0.238(4)	—	588(16)	637(16)	—	—	235.6(7)	—	7.15(7)	4.30(5)	45.50	—	—	54
—	—	2.212	5.924	69.0[h]	0.145(7)	0.325[h](7)	—	—	—	—	166.7(14)	—	—	—	—	—	—	55
—	—	0.5880	22.28	114.7	0.5002(10)	1.114[h](7)	359(16)	434(16)	—	—	587.2(14)	—	3.57(7)	15.50(5)	27.00	—	—	56
—	0.9996(15)	1.000	13.10	—	0.2400(9)	—	—	—	—	—	92.(3)	—	—	—	—	—	—	57
—	1.0006	0.0696	188.2	—	3.408(13)	—	274[r](13)	324[r](13)	—	—	193.9(14)	—	2.38(7)	4.00(5)	74.20	—	—	58
0.0213	—	1.105	11.86	—	0.2188(13)	—	—	—	—	—	91.6(14)	—	—	—	—	—	—	59
0.040	0.9997(15)	0.9672	13.55	—	0.2482(13)	—	—	—	—	—	87.8(14)	—	—	—	—	—	—	60
—	—	2.448	5.351	63.1	0.119(7)	—	—	—	—	—	123.8(14)	—	—	—	—	—	—	61
—	—	0.6220	21.06	175.6	0.4446(13)	1.0009(7)	—	—	—	—	970.3(12)	1.3330(8)	—	—	—	—	—	62
—	—	1.259	10.41	74.3	0.190(7)	—	—	—	—	—	185.5(14)	—	—	—	—	—	—	63

See the following pages for references

REFERENCES AND NOTES FOR TABLE 2

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NOTES

(a) Air saturated hydrocarbons.

(b) Absolute values from weights in vacuum.

(c) The apparent values from weight in air are shown for users' convenience and compliance with ASTM-IP Petroleum Measurement Tables. In the United States and Great Britain, all commercial weights are required by law to be weights in air. All other mass data are on an absolute mass (weight in vacuum) basis.

(d) At saturation pressure (triple point).

(e) Sublimination point.

(f) The + sign and number following signify the octane number corresponding to that of 2, 2, 4 trimethylpentane with the indicated number of ml of TEL added.

(g) Determined at 212°F.

(h) Saturation pressure and 60°F.

(i) Apparent value for methane at 60°F.

(j) Average value from octane numbers of more than one sample.

(k) Specific Gravity, 119 F/60°F (Sublimation point).

(m) Density of liquid, gr/ml at normal boiling point.

(n) Heat of sublimation.

(p) Values in parenthesis are estimated.

(q) Calculated from other properties.

(r) Values at 77°F.

(s) Extrapolated to room temperature from higher temperature.

(t) Values for Cp in ideal gas column for i-C_5 n-C_5 n-C_6 n-C_7 and n-C_8 are for information only. For components 31 thru 64 Cp shown for either gas or liquid depending on the physical state at 60°F and 14.696 psia or as otherwise noted.

*Calculated Values

CONSTANTS FOR USE IN CALCULATIONS

Atomic weights: carbon - 12:01; hydrogen - 1.008; 1 gal = 3785.41 milliliters

Molecular weight of air = 28.966
1 cu ft = 7.4805 gal
1 cu ft = 28.317 liters
1 lb = 453.59 grams
Ideal gas @ 60° F and 14.696 lb/sq in abs = 379.49 cu ft/lb mol
Ideal gas @ 32°F and 14.696 lb/sq in abs = 22.414 liters/gram mol
760 mm Hg = 14.696 lb/sq inch. = 1 atm
0°F = 459.69° Rankine
Density of water @ 60°F = 8.3372 lb/gal = 0.999015 g/cc (weight in vacuum)
Sp gr @ 60°F/60°F × 0.999015 = density at 60°F in g/cc

$$°F = 1.8\,(C° + 40) - 40$$

$$°API = \frac{141.5}{\text{sp gr @ }60°F/60°F} - 131.5$$

CALCULATED VALUES

Density of Liquid @ 60°F and 14.696 psia

Lb/gal @ 60°F (weight-in-vacuum) = sp gr @ 60°F × 8.3372 lb/gal (weight-in-vacuum).

Lb/gal @ 60°F (weight-in-air) = See ASTM 109A pg. 61 and API "Physical Constants of Hydrocarbons (1961) pg. 4.

$$\text{Gal/lb mol @ }60°F = \frac{\text{mol wt}}{\text{lb/gal @ }60°F\text{ (weight-in-vacuum)}}.$$

Temperature Coefficient of Density. See ASTM 109A pg. 61 and API "Physical Constants of Hydrocarbons" (1961) pg. 5.

Density of Gas @ 60°F and 14.696 psia (Ideal Gas)

$$\text{Sp gr @ }60°F = \frac{\text{mol weight}}{28.966}$$

$$\text{Cu ft gas/lb} = \frac{379.49}{\text{mol wt}}$$

$$\text{Cu ft gas/gal liq} = \frac{\text{lb/gal @ }60°F\text{ (weight-in-vacuum)} \times 379.49}{\text{mol wt}}$$

Heat of Combustion @ 60°F. See ASTM pp. 61, 62 and API "Physical Constants of Hydrocarbons" (1961) pg. 5.

Air Required for Combustion (Ideal Gas) – $C_a H_b$

$$\frac{\text{Cu ft air}}{\text{Cu ft gas}} = \frac{(a + \frac{b}{4})}{0.2095}$$

See ASTM 109A pp. 61,62 and API "Physical Constants of Hydrocarbons" (1961) pg. 7.

PERFORMANCE TEST CODES

C00020