



Standard Test Methods for Limiting Oxygen (Oxidant) Concentration in Gases and Vapors¹

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1. Scope

1.1 These test methods cover the determination of the limiting oxygen (oxidant) concentration of mixtures of oxygen (oxidant) and inert gases with flammable gases and vapors at a specified initial pressure and initial temperature.

1.2 These test methods may also be used to determine the limiting concentration of oxidizers other than oxygen.

1.3 Differentiation among the different combustion regimes (such as the hot flames, cool flames and exothermic reactions) is beyond the scope of these test methods.

1.4 *These test methods should be used to measure and describe the properties of materials, products, or assemblies in response to heat and flame under controlled laboratory conditions and should not be used to describe or appraise the fire hazard or fire risk of materials, products, or assemblies under actual fire conditions. However, results of this test may be used as elements of a fire risk assessment which takes into account all of the factors which are pertinent to an assessment of the fire hazard of a particular end use.*

1.5 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 ASTM Standards:

E 681 Test Method for Limits of Flammability of Chemicals²

E 918 Practice for Determining the Limits of Flammability of Chemicals at Elevated Temperature and Pressure²

E 1445 Terminology Relating to Hazardous Potential of Chemicals²

2.2 NFPA Publication

NFPA 69, Standard on Explosion Prevention Systems³

2.3 NTIS Publications

Coward, H.F. and Jones, G.W., Bulletin 503, Bureau of Mines, "Limits of Flammability of Gases and Vapors," NTIS AD701575, 1952⁴

Zabetakis, M.G., Bulletin 627, Bureau of Mines, "Flammability Characteristics of Combustible Gases and Vapors," NTIS AD701576, 1965⁴

Kuchta, J.M., Bulletin 680, Bureau of Mines, "Investigation of Fire and Explosion Accidents in the Chemical, Mining, and Fuel-Related Industries - A Manual," NTIS PB87113940, 1985⁴

3. Terminology

3.1 *Definitions:* (see also Terminology E1445):

3.1.1 *flammable*—capable of propagating a flame.

3.1.2 *ignition*—the initiation of combustion.

3.1.3 *limit of flammability*—the boundary in composition space dividing flammable and nonflammable regions.

3.1.4 *limiting oxygen (oxidant) concentration (LOC) of a fuel-oxidant-inert system*—the oxygen (oxidant) concentration at the limit of flammability for the worst case (most flammable) fuel concentration.

3.1.4.1 *Discussion*—*Limiting oxygen (oxidant) concentration* is also known as *minimum oxygen (oxidant) concentration* or as *critical oxygen (oxidant) concentration*.

4. Summary of Test Method

4.1 A mixture containing one or more flammable components (fuel), oxygen (oxidant) and inert gas(es) (such as nitrogen, carbon dioxide, argon, etc.) is prepared in a suitable test vessel at a controlled initial temperature and made to the specified initial pressure. Proportions of the components are determined by a suitable means. Ignition of the mixture is attempted and flammability is determined from the pressure rise produced. The criterion for flammability is a pressure rise of $\geq 7\%$ above the initial absolute test pressure. Fuel, oxygen (oxidant), and inert gas proportions are varied between trials until:

4.1.1 *L*—The lowest oxygen (oxidant) concentration for which flame propagation is possible for at least one combination of fuel and inert gas (the "worst case" or most flammable

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² *Annual Book of ASTM Standards*, Vol 14.02.

³ National Fire Protection Association, P.O. Box 9101, Quincy MA 02269-9101.

⁴ National Technical Information Service, 5285 Port Royal Road, Springfield VA 22161.

fuel concentration range), and

4.1.2 *H*—The highest oxygen (oxidant) concentration for which flame propagation is not possible for the same worst case fuel concentration range, are identified.

NOTE 1—The 7% pressure criterion may not be appropriate for certain fuel and oxidant mixtures. This is also the case if the test enclosure volume is small, or when the ignition energy is substantially larger than 10 J. It is therefore a prudent practice to perform exploratory tests in the vicinity of limit mixtures to evaluate the validity of the selected pressure rise criterion. See, for example (1)⁵.

5. Significance and Use

5.1 Knowledge of the limiting oxygen (oxidant) concentration is needed for safe operation of some chemical processes. This information may be needed in order to start up or operate a reactor while avoiding the creation of flammable gas compositions therein, or to store or ship materials safely. NFPA 69 provides guidance for the practical use of LOC data, including the appropriate safety margin to use.

5.2 Examples of LOC data applications can be found in references (2, 3, 4).

5.3 Much of the previous literature LOC data (5, 6, 7) were measured in the flammability tube.

6. Limitations

6.1 These test methods are not applicable to mixtures which undergo spontaneous reaction before ignition is attempted.

6.2 These test methods are limited to mixtures which have maximum deflagration pressures less than the maximum working pressure of the test apparatus.

6.3 These test methods may be used up to the temperature limit of the test system.

6.4 Measurements of flammability are influenced by flame-quenching effects of the test vessel walls. Further surface effects due to deposits of carbon or other materials can significantly affect limits of flammability, especially in the fuel-rich region. Refer to Bureau of Mines Bulletins 503 and 627. For certain chemicals (for example, ammonia, halogenated materials, and certain amines) which have large ignition-quenching distances, tests may need to be conducted in vessels larger than that specified below.

7. Apparatus

7.1 The test vessel must have a volume of at least 4 L.

NOTE 2—A survey of practitioners of this method indicates that test vessels in the size range of 4 to 35 L are used.

7.2 Test vessels must be nearly spherical. The maximum aspect ratio of the test vessel (the ratio of largest to smallest internal dimension) must be smaller than or equal to two.

7.3 Test vessel may be equipped with a means of mechanical agitation to ensure uniform mixing of components before an ignition attempt.

7.4 If tests are to be conducted at an elevated temperature, the test vessel may be heated using a heating jacket, heating mantle or placed inside a heated chamber. The heating system

must be capable of controlling the gas temperature inside the test vessel to within $\pm 3^{\circ}\text{C}$ both temporally and spatially. An appropriate device such as a thermocouple should be used to monitor the gas temperature within the test vessel.

7.5 Ignition point must be positioned near the center of the vessel and away from any surfaces or obstacles inside the test vessel.

7.6 One design of an acceptable test vessel is described in Appendix X1.

7.7 The maximum allowable working pressure (MAWP) of the test vessel at the maximum test temperature must exceed the maximum expected deflagration pressure.

7.8 Pressure Transducers:

7.8.1 *Low-Range Transducer*—A low-range pressure transducer may be used for the purpose of making partial pressure additions of gases and vapors to the test vessel. The transducer and its signal conditioning/amplifying electronics should have an accuracy, precision and repeatability sufficient to accurately resolve the required changes in the gas partial pressure for the component used in lowest concentration. The transducer should be protected from deflagration pressures by means of an isolation valve. A pressure gage may be used if an error analysis is performed to demonstrate that the internal volume of the pressure gage and piping will not significantly affect the test mixture.

7.8.2 *High-Range Transducer*—This transducer has the purpose of measuring the pressure rise on ignition of the gas mixture. It should have sufficient range to withstand the highest pressure it is expected to experience while also having sufficient accuracy and resolution to measure small pressure rises of the order of 7 % of the initial absolute test pressure.

7.8.3 The pressure transducer and recording equipment must have adequate time resolution to capture the maximum rate of pressure rise developed by the combustion event.

7.8.4 Calibration of the pressure transducer and data acquisition system must be verified over the range of pressures at which the system is expected to operate.

7.9 *Ignition Source*—Several possible means of ignition may be used which include those described below. The means of ignition used must be described in the test report.

7.9.1 *Fuse Wire*—A fuse wire igniter can be constructed, for example from a piece of No. 40 (0.076 mm diameter) copper, nichrome or platinum wire fastened to power supply terminals in such manner as to leave a filament of wire between the terminals approximately 10 mm long. A 500 VA/115 V isolating transformer, or a properly sized discrete discharge capacitor circuit will serve as an adequate igniter energy supply.

7.9.2 *Carbon Spark*—Four 2 mm diameter graphite rods wrapped by the leads coming from an electrical pulse generator. The two electrical leads are separated by a 6 to 10 mm distance. The resulting discrete spark is in the form of a surface discharge over the graphite rods.

7.9.3 *Continuous Electric Arc*—An electric arc igniter may consist of a pair of electrodes (steel or graphite) spaced approximately 6 mm apart across which a 30 mA arc of typically less than 1 s duration can be supplied from a

⁵ The boldface numbers in parentheses refer to the list of references at the end of this standard.



115/15 000 volt transformer (so-called luminous tube transformer).

7.9.4 Discrete Electric Spark—An electric spark igniter may consist of a pair of electrodes (steel or graphite) spaced approximately 6 mm apart across which a short duration spark (lasting for typically 1 ms or less) is caused to occur upon a single discharge of a capacitor. The electrical energy stored on or discharged from the capacitor, or both, should be measured and reported. The energy dissipated in the spark gap may also be measured by appropriate means. Use of at least 10 Joules of nominal (stored) spark energy is recommended.

NOTE 3—Electric arcs and sparks listed in 7.9.3 and 7.9.4 may fail to discharge when testing fuels with high dielectric strength and during tests conducted at a high initial pressure.

7.9.5 Chemical Igniter—Some materials (such as chloro-fluoro-carbons) require a higher ignition energy than that can be provided by the electrical means described above. In that case, tests with chemical igniters (for example, electric matches, electrically activated kitchen match heads, or Sobbe igniters) may be necessary to determine the true limiting oxidant concentration (or the flammability limit) as opposed to an “ignitability limit.” If tests are conducted in a sufficiently large vessel, electric matches or Sobbe igniters may be used. However, it should be kept in mind that these igniters produce significantly larger and sometimes multiple ignition kernels than the electrical ignition sources. Chemical igniters are likely to overdrive combustion events in small test vessels, and in that case, measured LOC values are expected to be lower than the actual LOC values. If a chemical igniter is used, the pressure rise from the igniter, by itself, must be determined. During a test, there is also an additional pressure generated by the combustion of the fuel gas within the igniter flame, even though there is no propagation. One way to partially correct for these igniter effects is to use a more stringent ignition criterion than the standard 7 % pressure rise. Appropriate ignition criterion may be determined from a series of baseline tests conducted on actual fuel-oxidant-diluent mixtures chosen near the non-flammable vicinity of the composition H defined in Section 4.

NOTE 4—Igniters dissipating large quantities of energy (especially chemical igniters) are capable of producing a finite pressure rise in the smaller test vessels, even in the absence of flammable test mixtures. The pressure rise due to igniter must be quantified before the LOC testing, and must be subtracted from the peak pressure rise measured at each test (see 10.1.11). If the pressure rise due to igniter is a non-negligible fraction of the absolute pressure of the test mixture, the accompanying compressive heating of the test mixture must be considered.

NOTE 5—Some igniters may not be capable of dissipating all or any of their rated energy at the extremes of pressure and temperature. If there is any doubt, the reliability of the igniter function must be demonstrated at the test conditions.

8. Safety Precautions

8.1 Adequate shielding must be provided to prevent injury in the event of equipment rupture. The apparatus should be set up so that the operator is isolated from the test vessel while the vessel contains a charge of reactants, including the time while the vessel is being filled. The test apparatus should be equipped with interlocks so that the ignition source cannot be activated

unless the operator has taken necessary steps to protect personnel and equipment. Activation of the ignition source should be possible only from a position shielded from the test vessel. The test vessel may be fitted with a rupture disk vented to a safe location.

8.2 In the selection of the safe location for the vessel discharge, whether it is through discharge piping or through a rupture disk, full consideration should be given to the safety of the personnel, environment and property. The impact of both unburnt and burnt test mixture venting must be considered, and necessary protection and mitigation measures must be implemented.

8.3 If the fuel can inadvertently be vented inside the heated chamber or inside the enclosed area, the heated chamber should be fitted with an inert gas purge or the area should be adequately ventilated to prevent buildup of an flammable mixture in the large space.

8.4 It is recommended that LOC evaluations be performed at atmospheric pressure prior to conducting evaluations at elevated initial pressure. This measure should provide baseline data which will help to avoid unexpectedly energetic explosions at high initial pressure.

8.5 Where the LOC is expected to exceed 21 %, testing should begin at 21 % oxygen and the oxygen concentration should be increased in small increments.

NOTE 6—The maximum deflagration pressure that can be developed during the test should be estimated by a suitable means, before testing.

8.6 Test matrix must be planned carefully to avoid testing of detonable mixtures.

8.7 Compressed gas cylinders should be secured by means appropriate to the size of cylinder. Gas cylinder valves should be closed when not in use. Gas cylinders should be fitted with pressure regulators of the correct pressure range and type suited for use with the gas contained therein. Regulator delivery pressure should be set to the lowest value required for efficient gas transfer. The use of check valves in gas supply lines is recommended. All connections in gas transfer lines should be checked for tightness.

8.8 Where oxidizers stronger than air are used, the potential safety consequences of enhanced reactivity must be addressed.

9. Preparation of Apparatus

9.1 Clean and dry the test vessel and other gas-handling equipment. Make sure that no oil, grease, or other combustible is left inside the parts.

9.2 Assemble the test system components and check for leak points.

9.3 Verify that the test system is at the required operating temperature and check for leaks.

10. Procedure

10.1 Two different test methods are used depending on the state of the fuel at room temperature:

TEST METHOD A—WHERE SAMPLE COMPONENTS ARE GASES AT ROOM TEMPERATURE

10.1.1 Connect the gas supply lines to the manifold of metering valves and flush the lines.

10.1.2 Verify that the test vessel has been thoroughly purged of gases from prior tests.

10.1.3 Evacuate the test vessel and manifold, as required. By use of the valves, add to the test vessel the component most appropriately added first; usually, this is the component to be used in the smallest amount. Record the partial pressure of this component using the low range-transducer.

10.1.4 If the internal volume of the manifold or any piping system connected to the test vessel is appreciable compared to the test vessel volume, purging, evacuation or other measures must be implemented to ensure the accuracy of the test mixture.

10.1.5 Add the second component up to the desired pressure, as measured by the transducer. Repeat the procedure to introduce other components until the desired partial pressure of each component has been added to the test vessel. Obtain mixing of gas in the test vessel by adding the largest component last and at high velocity. Where the vessel configuration will permit, an internal mixing device may be used.

10.1.6 Allow the test gas mixture to equilibrate in temperature and pressure after the addition of each component.

NOTE 7—Self reactions such as polymerization may occur and can affect the vapor concentration and composition.

NOTE 8—If the pressure and temperature do not achieve a steady state value after a component is added, this may indicate reaction prior to ignition. Reaction of oxygen (oxidant) will probably cause a pressure rise.

10.1.7 Close the valve between the test vessel and the low-range pressure transducer in order to protect this transducer from deflagration pressure.

10.1.8 Ensure uniform mixing of the components before attempting ignition. The mixing may be achieved by an internal fan, recirculation, or rapid addition of the major component which is added last. Mixture uniformity may be confirmed by gas analysis.

10.1.9 Test mixtures prepared using the partial pressure method may not have the composition expected, due to non-ideal gas behavior. The composition error may vary with the order of mixing, temperature, pressure, and the particular materials. Also, the greater the dead volume in tubing etc., not involved in mixing with the charge in the test vessel, the greater will be the difference from expected composition. Early in the test series an appropriate method such as gas analysis may be used to confirm composition of gas mixtures made ready for the test. Alternatively, an appropriate non-ideal gas mixture model may be used to quantify the magnitude of the concentration errors. This information may be used to correct the test mixture compositions and to set error bounds on the reported data.

10.1.10 Carbon deposits are likely to affect test results. The test vessel should be inspected periodically to determine whether carbon deposits may have formed on the vessel walls. Such deposits should be removed by suitable means which may include mechanical cleaning, fuel-lean deflagrations, or other cleansing techniques.

10.1.11 Record the initial temperature and pressure (absolute) of the test mixture in the test chamber.

10.1.12 Activate the ignition source.

10.1.13 Record the maximum pressure achieved. Subtract

from the maximum pressure the initial pressure and the pressure contribution due to action of the ignition source alone. The result is the net pressure rise due to combustion. Record the result as a *Go* (ignition and subsequent flame propagation) if the net pressure rise is greater than or equal to 7 % of the initial test pressure. Otherwise classify the result as a *No-Go* (*non-ignition*).

10.1.14 Vent the test vessel through the exhaust valve. Purge the vessel with inert gas.

NOTE 9—The venting should be to a safe location since the vented gases may form a flammable mixture when mixed with air. See 8.2.

10.1.15 *Inspect the Igniter*—If it is a one-time device (for example, fuse wire, or a chemical igniter), verify visually that it has functioned in the intended manner. If it is a multiple use device (for example, an electric spark) verify that it still conforms to the igniter specifications.

10.1.16 Vary fuel-oxygen (oxidant)-inert concentrations (partial pressures) as required to find the limiting oxygen (oxidant) concentration for all possible combinations of the specified fuel and inert components. The most flammable (worst case) fuel-inert concentration combination is likely to vary with oxygen (oxidant) concentration. A number of search algorithms can be devised and used to find the LOC. The following procedures have been used successfully:

10.1.16.1 Calculate or estimate the stoichiometric fuel concentration for the oxidizing gas (air or other oxidant being used). Appendix X2 provides a calculation procedure for a generalized fuel and air. Use this fuel concentration in the first series of tests. Conduct first test near an estimated value of the LOC. A composition with an oxygen (oxidant) volume fraction of 10 to 12 % may serve as a practical starting point in many cases. Alternatively, the LOC may be estimated by calculating the product of the lower flammability limit (in volume percent) and the stoichiometric O₂ to fuel molar ratio.

NOTE 10—In order to keep the number of tests at a minimum, different LOC search algorithms may be used for different fuels. The stoichiometric fuel concentration is proportional to the oxygen (oxidant) concentration as the oxygen concentration is reduced to reach the LOC. The most reactive (worst case) mixture usually falls on the rich side of the stoichiometric concentration. Therefore, keeping the fuel concentration, rather than the mixture stoichiometry, constant for the first test series may provide a more efficient convergence to LOC in higher hydrocarbons. On the other hand, following the stoichiometric line may be more efficient for lower hydrocarbons. If the test procedure is followed correctly, the LOC result will be independent of the initial search algorithm used.

10.1.16.2 Calculate the partial pressures of fuel, oxygen (oxidant), and inert required to both achieve the desired fuel concentration and to establish the desired test oxygen (oxidant) concentration.

10.1.16.3 Vary the oxygen (oxidant) concentration until a preliminary value of the minimum oxygen concentration that supports combustion is found. Then vary the fuel to find the range of concentrations that are flammable. Then conduct tests at the next lower oxygen concentration to determine if any mixtures are ignitable.

10.1.16.4 Repeat this procedure until the lowest oxygen (oxidant) concentration which supports combustion has been determined for any combination of components, that is, the “worst case”.



10.1.17 Using some search algorithm such as those in 10.1.16, the proportions of fuel, oxygen (oxidant) (air), and inert gas are varied to identify:

10.1.17.1 L—The lowest oxygen (oxidant) concentration for which flame propagation is possible for at least one combination of fuel and inert gas (the “worst case” or most flammable fuel concentration range), and

10.1.17.2 H—the highest oxygen (oxidant) concentration for which flame propagation is not possible for the same worst case fuel concentration range.

10.1.17.3 At the LOC, the span between *L* and *H* should be no more than 1.0 vol %.

NOTE 11—This definition will result in the fuel - inert gas mixture compositions for *H* and *L* coinciding with each other.

10.1.18 An aid to selecting new fuel concentration values is a graphical plot (see Appendix X3) of the *L* and *H* values on a graph of oxygen (oxidant) volume per cent vs fuel concentration. It is the minimum of the curve drawn through data plotted in this manner that is the desired result of this procedure. Note that the figure contains more data at concentrations well above the LOC than is required for the test; the additional data were presented to show how the flammable range varies with oxygen concentration. The figure also shows finer steps in oxygen concentration than is required by this test method.

10.1.19 Record the values for *L* and *H*. Make at least one duplicate test for the mixture *H* to confirm that this indeed produces a No-Go result.

TEST METHOD B—SAMPLE COMPONENTS WHICH ARE LIQUIDS AT ROOM TEMPERATURE

10.2 Set up the equipment as described in Test Method A except for the introduction of fuel. It is recommended to add the fuel first into the evacuated test chamber using one of the three techniques described below.

10.2.1 Fuel introduced as heated vapors or heated liquid. Fuel is placed in a small pressure vessel which is either independently heated or placed inside the chamber used to heat the test vessel. The fuel container is fitted with a remotely controlled needle valve. If the fuel will evaporate without fractionation, place the valve in contact with the vapor phase in the cylinder. Otherwise, place the needle valve in contact with the liquid phase even though this makes control of the flow more difficult. In tests conducted at elevated temperature, avoid having unheated sections of the test vessel or connected tubing.

NOTE 12—LOC tests may be conducted at any combination of temperature and pressure required for the application. For routine reporting purposes, LOC tests are normally conducted at atmospheric temperature and pressure. If the fuel is liquid at room temperature, then it is necessary to test at elevated temperature to ensure rapid and complete evaporation of the fuel and to avoid condensation in the vessel and in the connected lines. To facilitate reporting and tabulation of the “routine” LOC data, it is desirable to standardize the elevated test temperatures. Two meaningful “elevated” test temperatures are 60 and 93°C, which are internationally-recognized flashpoint demarcations used in fire hazard classification systems for liquids.

NOTE 13—The cylinder of liquid fuel must be fitted with a pressure-relief device which discharges outside the heated chamber and outside any other structure which would confine the material. Fuels which might undergo hazardous reaction in the heated cylinder must not be tested by this procedure. If any uncertainty exists as to whether the sample may

react in the heated chamber, thermal stability testing should be performed.

10.2.2 Fuel introduced as cold liquid. An alternative method of adding liquid fuel to the test vessel is by laboratory syringe. It is necessary to affix to the test vessel a syringe port that can be mechanically isolated. This may be achieved using a small ball or plug type valve with a septum fitting on its inlet port. With the test vessel evacuated a measured quantity of liquid fuel may be injected into the vessel manually. If the injection needle is not long enough to extend all the way inside the test vessel, the user must take the necessary steps to ensure that there is no condensation near the point of injection. Condensate can also accumulate at the bottom of the test vessel. Thermocouples can be used to check for condensation in critical locations.

NOTE 14—Use of procedure in 10.2.2 requires extreme caution due to exposure to heated surfaces and the need to provide positive lockout of the oxygen (oxidant) source to prevent premature oxygen (oxidant) addition while making fuel addition.

10.2.3 After the desired amount of fuel is introduced into the test vessel, allow time for mixing and thermodynamic equilibration. Then proceed with the remaining component additions and procedure as described in 10.1.3 and following paragraphs.

11. Calculation

11.1 Calculate the limiting oxygen (oxidant) concentration from the values of *L* and *H* determined above as follows:

$$\text{LOC} = (L + H)/2 \quad (1)$$

The LOC value should be rounded down to the nearest 0.5 % oxygen, unless the steps in oxygen concentration are fine enough to allow greater precision.

NOTE 15—Limit concentrations, *L* and *H*, are usually reported in terms of volume percent. It is sometimes appropriate to report limits in terms of weight per unit volume at the test conditions, particularly with multi-component fuels or materials exhibiting a high degree of non-ideal vapor phase behavior.

12. Report

12.1 Report the following information:

12.1.1 Identification of materials used including fuel, oxidizing agent, and inert gas. Include chemical name, trade name, purity and source as appropriate.

12.1.2 Method used to determine the test mixture compositions, for example, partial pressure method using ideal gas approximation, partial pressure method accounting for some (specify) non-ideal gas effects, gas analysis, gas chromatography,

12.1.3 Description of the test vessel (including volume), ignition source (ignitor type and ignition energy delivered). Descriptions of the measurement and data collection system, calibration, and the test procedure may be included,

12.1.4 Minimum pressure rise criterion used to deduce ignition,

12.1.5 Any deviations from these test methods,

12.1.6 Table of data (including, for each test, initial temperature and pressure, concentration of each species in the mixture, maximum pressure rise obtained after the igniter actuation, and classification of result as a *Go* or *No-Go*) should

be included (see Table X3.1 for example),

12.1.7 Graphical presentation of data should be included (see Fig. X3.1 for example),

12.1.8 Test temperature and pressure, and

12.1.9 LOC value, plus L and H values.

13. Precision and Bias

13.1 *Precision*—Measurement of LOC by this method

should be repeatable to within 1 vol % oxygen (oxidant) for a particular igniter.

13.2 *Bias*—Insufficient data have been developed and analyzed to determine the bias of these test methods.

APPENDIXES

(Nonmandatory Information)

X1. SCHEMATIC DIAGRAM OF AN ACCEPTABLE TEST VESSEL

X1.1 The test vessel shall be nearly spherical of metal construction having a volume not less than 4 L and a maximum aspect ratio of two.

X1.2 An schematic diagram of an acceptable test vessel configuration is shown in Fig. X1.1. It consists of hemispherical halves held together by a bolting arrangement. Threaded

fittings allow for attachment of igniter assembly, pressure transducer, thermocouple, inlet and vent ports. Igniter is located near the center of the spherical test vessel. Different thermocouples (not shown) are placed to measure initial temperature, to sense the presence of the flame or condensate.

X1.3 The test vessel may be heated using a heating jacket, heating mantle or placed inside a heated chamber.

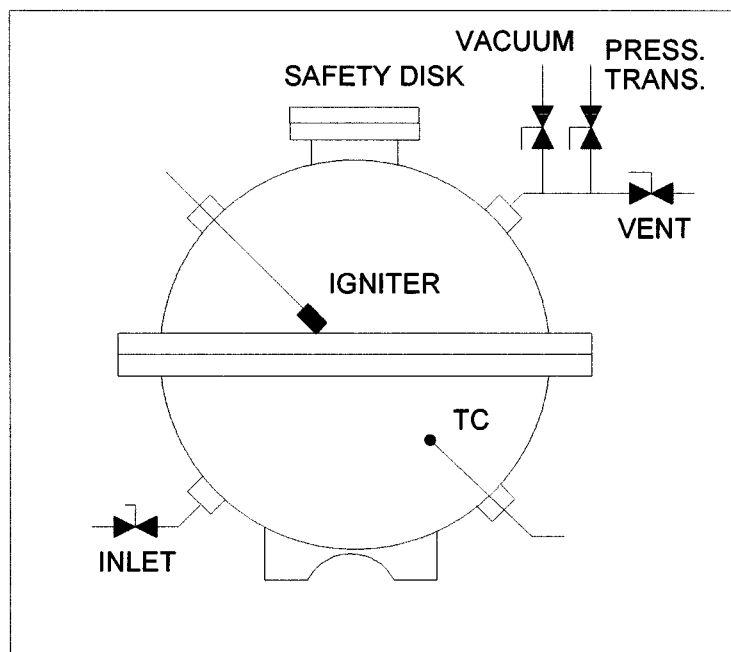


FIG. X1.1 7.85 L Spherical Test Vessel

X2. CALCULATION OF THE STOICHIOMETRIC FUEL CONCENTRATION IN AIR

X2.1 *Fuel Chemistry*—Determine or estimate the average molecular composition of the fuel as:

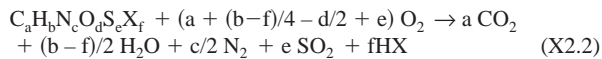


where in the molecular formula the subscripts represent the number of atoms as follows:

- a = carbon,
- b = hydrogen,
- c = nitrogen,
- d = oxygen,
- e = sulfur, and
- f = halogen (F, Cl, Br, I).



X2.2 *Reaction Stoichiometry*—The complete reaction of the fuel with oxygen at the stoichiometric mixture ratio can be assumed, for the purposes of this procedure, to proceed as follows if $b \geq f$:



X2.3 *Stoichiometric Mixture*—A mixture having the proportions of fuel and oxygen (oxidant) which combine according to the global reaction given in X2.2 is a stoichiometric mixture.

X2.4 The composition of standard dry atmospheric air is as

follows (from *Handbook of Chemistry and Physics*, 68th ed., CRC Press, Boca Raton, FL, 1987).

Nitrogen	78.084 vol %
Oxygen	20.9476 vol %
Argon	0.934 vol %
Carbon Dioxide	0.0314 vol %
Other	0.003 vol %

X2.5 The stoichiometric concentration of fuel vapor in air is calculated as follows:

$$\text{Stoic. Conc.} = 1/\{1 + (a + (b-f)/4 - d/2 + e)/0.209476\} \times 100 \text{ vol \%} \quad (X2.3)$$

X3. EXAMPLE DATA TABLE AND GRAPHICAL PRESENTATION

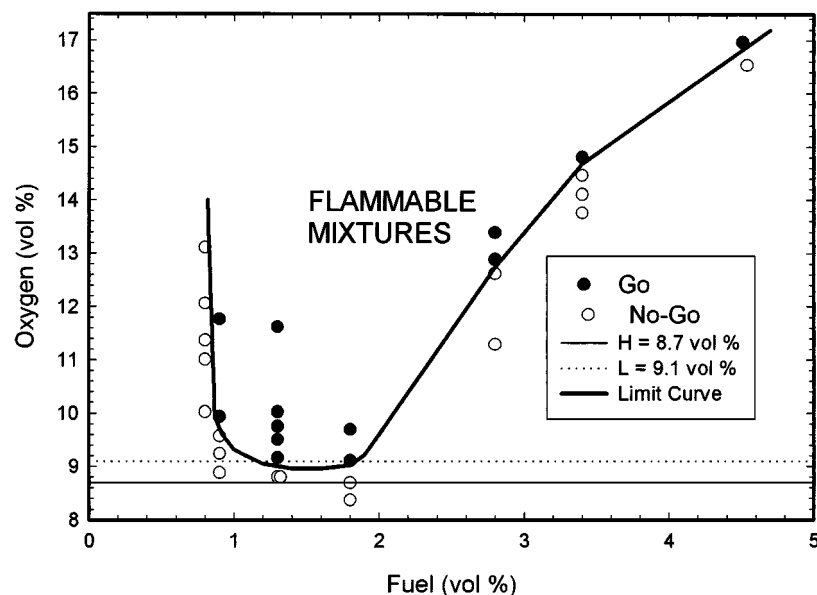
X3.1 Graphical summary of data is given in Table X3.1.

TABLE X3.1 Portion of the Test Data on Flammability of an Hydrocarbon-Air-Nitrogen System

NOTE 1—Test Conditions: $P_o = 101.3 \text{ kPa}$ (14.7 psia), $T_o = 177 \pm 3^\circ\text{C}$ ($350 \pm 5^\circ\text{F}$) Test Vessel Volume = 7.85 L ignition source: short duration spark, nominal ignition energy 60 J. The fuel was a C8 hydrocarbon. Fuel plus added nitrogen plus air equals 100 %. Ambient air was the source of oxygen. Added nitrogen was from a commercial high pressure cylinder. Oxygen values were calculated as 21 % of the air values.

NOTE 2—Test data set partially shown in this table and plotted on Fig. X3.1 has a finer resolution and covers a wider range of fuel concentrations than that required by this standard.

Test Number	Fuel Vol %	Added N ₂ Vol %	Air Vol %	Oxygen Vol %	Pmax psig	Result Go/No-Go
1	3.4	26.1	70.5	14.8	2.5	Go
2	3.4	27.7	68.9	14.5	0.9	No-Go
3	3.4	29.4	67.2	14.1	0.7	No-Go
4	3.4	31.1	65.5	13.8	0.3	No-Go
5	2.8	33.4	63.8	13.4	6	Go
6	2.8	35.8	61.4	12.9	1.6	Go
7	0.8	36.8	62.4	13.1	0	No-Go
8	2.8	37.1	60.1	12.6	0.8	No-Go
9	0.8	41.8	57.4	12.1	0	No-Go
10	0.9	43.1	56	11.8	37.3	Go
11	1.3	43.4	55.3	11.6	29.4	Go
12	2.8	43.4	53.8	11.3	0	No-Go
13	0.8	45.1	54.1	11.4	0	No-Go
14	0.8	46.8	52.4	11	0	No-Go
15	1.3	51	47.7	10	5.4	Go
16	0.8	51.5	47.7	10	0	No-Go
17	0.9	51.8	47.3	9.9	6.5	Go
18	1.8	52	46.2	9.7	1.8	Go
19	1.3	52.3	46.4	9.8	7	Go
20	1.3	53.5	45.2	9.5	4.8	Go
21	0.9	53.5	45.6	9.6	0.8	No-Go
22	1.8	54.8	43.4	9.1	2.2	Go
23	1.3	55.1	43.6	9.2	3.8	Go
24	0.9	55.1	44	9.2	0	No-Go
25	1.8	56.8	41.4	8.7	0	No-Go
26	1.3	56.8	41.9	8.8	0	No-Go
27	1.3	56.8	41.9	8.8	0	No-Go
28	0.9	56.8	42.3	8.9	0	No-Go



NOTE 1—This figure contains more data points than shown in Table X3.1. The data set has a finer resolution and covers a wider range of fuel concentrations than that required by these test methods.

NOTE 2—Summary of Results:

L = 9.1 vol% oxygen at 1.8 % fuel vapor,

H = 8.7 vol% oxygen at 1.8 % fuel vapor, and

LOC = 8.9 vol% oxygen at 1.8 % fuel vapor, 42.4 % air and 55.8 % added nitrogen.

FIG. X3.1 Flammability Test Results Obtained for a Hydrocarbon Vapor-Air-Nitrogen System at 101 kPa (14.7 psia) Initial Pressure and a Test Temperature of 177°C (350°F)

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