

IEEE Standard for the Testing, Design, Installation, and Maintenance of Electrical Resistance Heat Tracing for Industrial Applications

Sponsor
**Petroleum and Chemical Industry Committee
of the
Industry Applications Society**

Approved 20 March 1997
IEEE Standards Board

Approved 20 August 1997
American National Standards Institute

Abstract: The specific test requirements for qualifying electrical resistance heating cables for industrial service are provided, as well as the basis for electrical and thermal design. Heating device characteristics are addressed, and installation and maintenance requirements are detailed. Heating cable and surface heating device application recommendations and requirements are made for ordinary (unclassified) and hazardous (classified) potentially flammable atmospheres and locations.

Keywords: electrical design, heat tracing, pipelines, series heating cables, surface heating devices, thermal design

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Introduction

(This introduction is not part of IEEE Std 515-1997, IEEE Standard for the Testing, Design, Installation, and Maintenance of Electrical Resistance Heat Tracing for Industrial Applications.)

The utilization of electrical resistance heat tracing by industry has steadily increased because of the availability of more reliable products and efficient operation. The need for broad-based technical information about electrical resistance heat-tracing systems and uniformity in the approval process for these systems provides the need for this standard.

IEEE Std 515-1997 provides the specific test requirements for qualifying electrical resistance heating cables and surface heating devices for industrial service, as well as the basis for electrical and thermal design. Type and routine production tests are outlined in this standard and address such topics as mechanical durability, resistance to moisture, and electrical and thermal ratings. This standard outlines specific requirements for the utilization of thermal insulation systems in conjunction with electrical resistance heat tracing. Installation and maintenance requirements are detailed and include electrical and mechanical requirements, along with those management functions that should be considered.

Detailed technical information and equations with examples on the thermal relationships important to electrical resistance heat tracing are presented in the annexes.

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IEEE Standard for the Testing, Design, Installation, and Maintenance of Electrical Resistance Heat Tracing for Industrial Applications

1. Overview

1.1 Scope

This standard provides requirements for the testing, design, installation, and maintenance of electrical resistance heat tracing in general industries as applied to pipelines, vessels, pre-traced and thermally insulated instrument tubing and piping, and mechanical equipment. The electrical resistance heat tracing is in the form of series heating cables, parallel heating cables, and surface heating devices. In this standard the terms hazardous (classified) locations and potentially flammable atmospheres refer to the same conditions. The requirements also include test criteria to determine the suitability of these heating devices utilized in industrial applications as applied in ordinary (unclassified) and hazardous (classified) locations as outlined below:

- Class I
 - Division 1
 - Division 2
 - Zone 1
 - Zone 2
- Class II
 - Division 1
 - Division 2
- Class III
 - Division 1
 - Division 2
- Ordinary (unclassified)

1.2 Purpose

The provisions of this standard should ensure that process, fluid, or material temperatures are maintained and provide electrical, thermal, and mechanical durability to the heat-tracing system, such that in normal use its performance is reliable and poses no danger to the user or surroundings. This standard is to serve as a complementary document to those national and international standards addressing electrical resistance heat tracing such as the National Electrical Code® (NEC®) NFPA 70-1996¹, Article 427; BS 6351-1983 [B4]², parts 1., 2., and 3.; EN 50019-1994 [B5]; IEC 79-0 (1983) [B9]; IEC 79-7 (1990) [B11]; and others.

2. References

This standard shall be used in conjunction with the following publications. When the following standards are superseded by an approved revision, the revision shall apply.

ASTM D 5025-94, A Laboratory Burner Used for Small-Scale Burning Tests on Plastic Materials.³

ASTM D 5207-91, Calibration of 20 and 125 mm Test Flames for Small-Scale Burning Tests on Plastic Materials.

NFPA 70-1996, National Electrical Code® (NEC®).⁴

NFPA 325-1994, Fire Hazard Properties of Flammable Liquids, Gases, and Volatile Solids.

NFPA 497M-1991, Classification of Gases, Vapors, and Dusts for Electrical Equipment in Hazardous (Classified) Locations.

3. Definitions

The following definitions apply to the subject matter presented in this standard:

3.1 ambient temperature: The temperature surrounding the object under consideration. Where electrical heating cable is enclosed in thermal insulation, the ambient temperature is the temperature exterior to the thermal insulation.

3.2 authority having jurisdiction: The organization, office, or individual that has the responsibility and authority for approving equipment, installations, or procedures.

3.3 certifying agency: Organization that validates that equipment meets tests and standards.

3.4 cold-lead connection: An electrically insulated conductor used to connect a heating conductor to the branch-circuit conductors and designed so as not to produce appreciable heat.

3.5 dead leg: A segment of process piping that is not in the normal flow pattern.

3.6 Division 1: Terminology used for classification of an industrial area in which flammable gases or combustible dusts can be present under normal conditions, or from frequent breakdowns, or where failure of equipment could release materials and create simultaneous failure of electrical equipment. (Refer to the NEC for a detailed definition.)

3.7 Division 2: Terminology used for classification of an industrial area in which flammable gases or combustible dusts will only be present under abnormal conditions. (Refer to the NEC for a detailed definition.)

¹Information on references can be found in Clause 2.

²The numbers in brackets correspond to those of the bibliography in Clause 9.

³ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA.

⁴NFPA publications are available from Publications Sales, National Fire Protection Association, 1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101, USA.

3.8 electrical insulation: A dielectric material that insulates each conductor from other conductors or from conductive parts at or near earth potential.

3.9 electrical resistance heat tracing: The utilization of electric heating cables, other electric heating devices, and support components that are externally applied and used to maintain or raise the temperature of fluids/materials in piping and associated equipment.

3.10 end termination connection: The termination applied to the end of a heating cable that may be heat producing, opposite where the power is supplied.

3.11 factory fabricated: A heating cable or surface heating device assembled by the manufacturer, including terminations and connections.

3.12 field assembled: Heating cable or surface heating device supplied in bulk form with terminating components to be assembled in the field.

3.13 heater de-energized maximum intermittent exposure temperature: The maximum temperature of any surface adjacent to the heating device that the de-energized heating device can withstand for specified periods.

3.14 heater energized maximum intermittent exposure temperature: The maximum temperature of any surface adjacent to the heating device that the energized heating device can withstand for specified periods.

3.15 heating device: Heating cable or surface heating unit.

3.16 heat loss: A quantitative value of energy flow from a pipe, vessel, or equipment to the surrounding ambient.

3.17 heat sink: A part that conducts and dissipates heat away from the pipe or equipment. Heat sinks, as related to pipe heating systems, can be pipe supports, valve operators, etc.

3.18 heat-transfer aids: Thermally conductive materials, such as metallic foils or heat-transfer cements, used to increase the heat-transfer rates from the heating cables to the process piping or equipment.

3.19 high-limit temperature: The maximum allowable temperature, including the piping, the fluid, and the heating system.

3.20 high-profile connection: Terminations or connections designed for use outside of the thermal insulation, or away from the surface being heated.

3.21 in-line connection: Connection of two heater cables together electrically in series or parallel on the same pipe.

3.22 low-profile connection: Terminations or connections designed to be an integral part of the heating cable and installed under the insulation.

3.23 maintain temperature: Specified temperature of the fluid or process material that the heat tracing is designed to hold at equilibrium under specified design conditions.

3.24 maximum continuous exposure temperature: The highest temperature to which a component of the heat-tracing system may be continuously exposed (heater de-energized).

3.25 maximum maintain temperature: Specified maximum temperature of a surface or process that the heat-tracing cable or surface heating device is capable of maintaining continuously.

3.26 metallic covering: A metal sheath or braid used to provide physical protection for heating cable and, in some cases, to provide an electrical ground path.

3.27 operating voltage: The actual voltage applied to the heating cable when in service.

3.28 over-size insulation: A term applied to thermal insulation when the inside diameter of the thermal insulation must be larger than the nominal outside diameter of a particular pipe so as to accommodate the heating cable.

3.29 parallel heating cable: Heating elements that are electrically connected in parallel, either continuously or in zones, so that watt density per lineal length is maintained irrespective of any change in length for the continuous type or for any number of discrete zones.

3.30 power termination connection: The termination applied to the end of a heating cable where the power is supplied.

3.31 rated output: The total power or power/unit length of heating cable or surface heating device, at rated voltage, temperature, and length normally expressed as W/m (W/ft) or kW.

3.32 rated voltage: The voltage to which operating and performance characteristics of heating cables are referred.

3.33 routine test: A test that is carried out by the manufacturer prior to shipment to verify conformance to the manufacturer's specifications.

3.34 runaway pipe temperature: The highest equilibrium pipe temperature that occurs when the heating cable is continuously energized at the maximum ambient temperature.

3.35 series heating cable: Heating elements that are electrically connected in series with a single current path and have a specific resistance at a given temperature for a given length.

3.36 sheath (overjacket): A uniform and continuous covering, metallic or nonmetallic, enclosing the insulated conductor(s), used to protect the cable against influences from the surroundings (corrosion, moisture, etc.).

3.37 sheath temperature: The temperature of the outermost continuous covering of a heating cable or surface heating device that may be exposed to the surrounding atmosphere.

3.38 start-up current: The current response of a heating cable or surface heating device following energization.

3.39 surface heating device (heating panel): A heater comprising series or parallel connected elements having sufficient flexibility to conform to the shape of the surface to be heated.

3.40 tee connection: Connection of heater in series or parallel to accommodate a branch on a pipe or equipment.

3.41 temperature class (T-rating): One of the values of temperature allocated to electrical heating devices derived from a system of classification according to the maximum surface temperature of the heater. Also referred to as T-class, identification number, T-rating, and temperature code.

3.42 temperature sensor (sensing element): A device that responds to temperature and provides an electrical signal or mechanical operation.

3.43 thermal insulation: Material having air- or gas-filled pockets, void spaces, or heat-reflective surfaces that, when properly applied, will retard the transfer of heat with reasonable effectiveness under ordinary conditions.

3.44 traced tube bundle: Pre-traced and thermally insulated instrument tubing that is used for fluid transport, containment, or conditioning system. The bundle is factory fabricated and consists of tubing, heating cable, thermal insulation, and weatherproof jacket.

3.45 type test: A test or series of tests carried out on heating cables or surface heating devices and accessories, representative of a type, to determine compliance of the design, construction, and manufacturing methods within the requirements of this standard.

3.46 weather barrier: Material that, when installed on the outer surface of thermal insulation, protects the insulation from water or other liquids; physical damage caused by sleet, wind or mechanical abuse; and deterioration caused by solar radiation or atmospheric contamination.

3.47 Zone 0: Terminology used for classification of an industrial area in which an explosive atmosphere is present continuously, or present for long periods of time during normal operation. {Refer to the NEC, Article 505, and IEC 79-10 (1995) [B12] for a detailed definition.}

3.48 Zone 1: Terminology used for classification of an industrial area in which an explosive atmosphere is likely to exist under normal operation. {Refer to the NEC, Article 505, and IEC 79-10 (1995) [B12] for a detailed definition.}

3.49 Zone 2: Terminology used for classification of an industrial area in which an explosive atmosphere is not likely to occur in normal operation, and if they do, they will exist only for a short period. {Refer to the NEC, Article 505, and IEC 79-10 (1995) [B12] for a detailed definition.}

4. General product testing

4.1 Type test—General purpose tests

The following tests are intended to qualify heating devices for the applications within the scope of this standard for ordinary locations. Samples of heating cable at least 3 m (10 ft) in length or representative surface heater section, unless otherwise specified, shall be selected for testing. Tests shall be conducted at room temperature between 10 °C–40 °C (50 °F–104 °F) unless otherwise noted. Annex E provides a matrix of test requirements for each heating cable or surface heating device application. All type tests shall be witnessed or verified by a certifying agency.

Terminations and connections that are to be installed as an integral part of the heating cable or surface heating device, whether intended to be factory fabricated or field assembled, shall be subjected to the same tests as the heating cable, except where noted otherwise. These should include low-profile power connections, splices, end terminations, as well as glands, fittings, and seals where a heating cable or surface heating device enters a termination enclosure. Applicable tests include dielectric, insulation resistance, water resistance, elevated temperature, deformation, cold impact, flammability, and termination's resistance to water. Annex E provides a matrix of test requirements for each termination or connection application.

4.1.1 Dielectric test

The dielectric test shall be performed by the manufacturer on the heating device in accordance with the following table:

Rated voltage	Test voltage (Vac rms)
≤ 30 V rms	500
≤ 60 Vdc	500
≥ 30 V rms	$2E + 1000$
≥ 60 Vdc	$\sqrt{2}E + 1000$

The test voltage where E = rated voltage shall be applied at a rate of rise neither less than 100 V/s nor more than 200 V/s and maintained for 1 min without dielectric breakdown.

The test voltage waveform shall be essentially sinusoidal, with a frequency of 45 Hz to 65 Hz. The test voltage shall be applied between the heating device's conductors and the metallic covering, or a specially applied conductive metal ground plane. Alternatively the dielectric test may be conducted by submerging the heating device in tap water at room temperature (resistivity typically 50 000 $\Omega \cdot \text{cm}$). The test voltage shall be applied between the heating conductors and the water.

4.1.2 Insulation resistance test

The insulation resistance shall be measured on the above sample after the dielectric test specified in 4.1.1. The resistance of the insulation shall be measured between conductors and the metallic outer covering, or a specially applied conductive metal ground plane, by means of dc voltage of 1000 Vdc for mineral insulated heaters and 2500 Vdc for polymer insulated heaters. The measured value shall not be less than 50 M Ω .

4.1.3 Water-Resistance test

A sample shall be immersed (except at terminations, or ends where the conductors are exposed) in tap water at 10 °C–25 °C (50 °F–77 °F) for a period of 14 days.

Within 1 h after conditioning as above, the sample shall be subjected to the dielectric test outlined in 4.1.1.

4.1.4 Connections/Terminations' resistance to water

For heating cables, a sample with factory or low-profile field assembled terminations shall be placed in a tap water flow and drain apparatus as shown in Figure 1. For surface heating devices, a unit with cold leads shall be used. The rate of the water flow shall be regulated to completely cover the heating device, including terminations, a minimum of every 5 min. The voltage to the water flow solenoid and the voltage applied to the heating device shall be controlled by a cam switch or equivalent means. The timing sequences shall be such that the heating cable or surface heating device shall be energized for 30 s after the water has been drained. The test shall be continued for a period of 24 h. After completion, the dielectric test outlined in 4.1.1 shall be performed. The end termination of the heating cable shall be inspected to verify no evidence of water ingress.

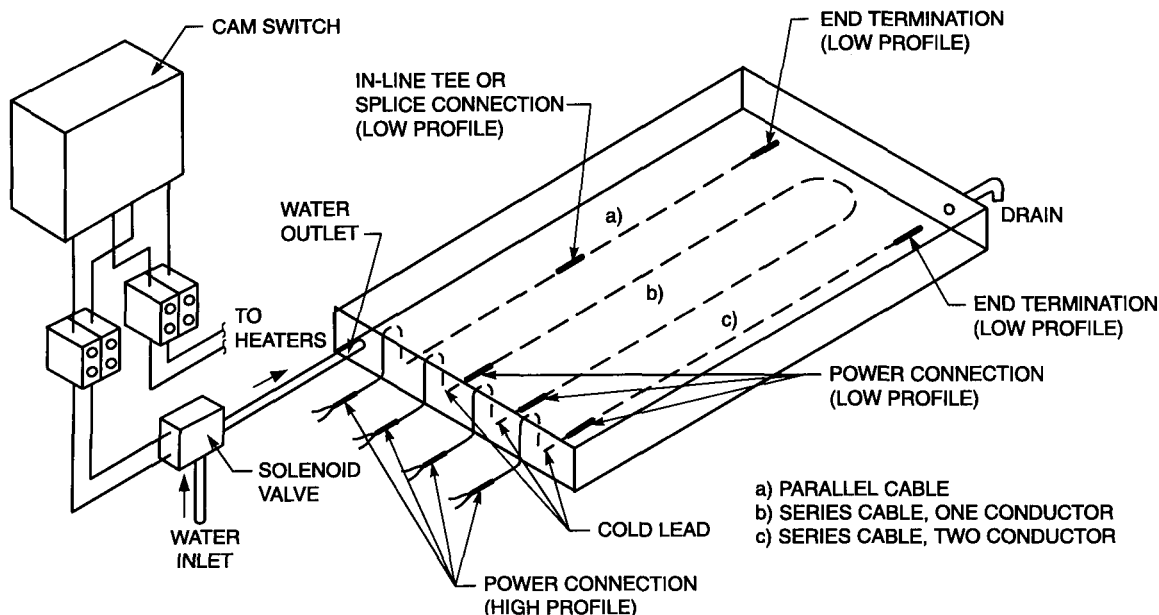


Figure 1—Heating cable termination and splice test apparatus

4.1.5 Elevated temperature exposure dielectric test

A sample of heating device shall be placed in a forced-circulation air oven. The oven shall be heated to, and maintained at, a temperature of 25 °C ± 5 °C (45 °F ± 9 °F) above the highest exposure temperature declared by the manufacturer for a period of 14 days.

The sample shall be removed from the air oven and cooled to room temperature. Heating cable samples shall be wound six close turns around a mandrel having a radius equal to twelve times the radius of the primary bending plane or thickness of the heating cable. Surface heating units, if flexible, shall be wrapped on a mandrel with a radius equivalent to the manufacturer's minimum recommended bending radius. While still on the mandrel the sample, except at terminations or ends where the conductor is exposed, shall be submerged in tap water at 10 °C to 25 °C (50 °F to 77 °F) for 5 min. While still in the tap water, the dielectric test outlined in 4.1.1 shall be performed. Rigid heating devices

shall also be submerged in tap water and tested. Upon completion of the test, the sample shall have no visible cracks when examined with normal vision.

4.1.6 Service life performance benchmark

Three randomly selected samples representing the maximum output of all cables or surface heating devices under evaluation shall be tested. If the type of cable or surface heating device has different levels of rated voltages and wattages, then three samples each shall be selected that represent 1) the lowest rated voltage level and the maximum rated output, and 2) the maximum rated voltage and the minimum rated output.

Samples shall be terminated according to the manufacturer's specifications, such that a heating length of at least 0.6 m (2 ft) or representative surface heating device dimensions is provided. The aging temperature of the test shall be the maximum declared maintain temperature of the heating device. The samples shall be conditioned, while energized, at the aging temperature for $120 \text{ h} \pm 24 \text{ h}$. The initial output of the samples is then to be determined by one of the three methods given in 4.1.11, with the exceptions of sample length and number of test temperature points for procedure 4.1.11 c). For this case, the samples shall be evaluated at rated voltage and at the manufacturer's stated reference temperature for the rated output. The output shall be within the manufacturer's stated output range.

The samples shall be attached to a fixture or suitable heat sink as described in 4.1.11 c), and insulated accordingly. The pipe or heat sink temperature shall be set to the specified aging temperature and maintained with $\pm 3 \text{ }^{\circ}\text{C}$ ($\pm 5.4 \text{ }^{\circ}\text{F}$) plus 1% of the temperature reading in degrees Celsius. Circulating fluid or external heating may be used to raise the fixture to the aging temperature. The samples shall be operated at rated output for series cables or rated voltage for parallel cable. Surface heating devices shall be operated at rated output. The power supply shall be attached to a 15 min cycle timer such that the samples are energized for 12 min and de-energized for 3 min. The samples shall be exposed to this conditioning for 32 weeks (5376 h).

For heating devices with an intermittent temperature exposure rating, the samples are exposed to the same conditioning for 32 weeks, except for an 8 h excursion once each week. At the beginning of the 8 h, the samples shall be disengaged from the cycle timer. The pipe or heat sink temperature shall be increased to a temperature equal to the manufacturer's stated intermittent exposure temperature. The time allowed to increase the temperature should be no greater than 1 h. After 7 h from the beginning of the excursion, the pipe or heat sink temperature shall be decreased back to the aging temperature, again allowing no more than 1 h for the operation. Where the intermittent temperature rating is based on the heating device being energized, then the heating device shall be continuously energized during this temperature excursion, except during cool down back to the maximum maintain temperature. Where the intermittent temperature rating is based on the heating device being de-energized, the exposure cycle is conducted in a de-energized condition. At the end of the 8 h excursion, the samples shall be re-engaged to the cycle timer. The excursions should occur on the same day each week.

At the end of the 32 weeks of operation at the continuous rated temperature, the output of the samples shall be determined by the same procedure as utilized for the initial readings. The percent change to the initial output shall be calculated. The heating cable or surface heating device shall not show an increase of more than 20% output; and the heating cable or surface heating device shall maintain a minimum of 75% of the initial output as determined in 4.1.11.

4.1.7 Deformation test

For heating devices a sample of heating cable or surface heating device and cold lead (if applicable), of at least 200 mm (8 in) in length, shall be used for testing. The ends of the sample shall be stripped back to expose the conductors. The sample shall be placed on top and at right angles to a 6 mm (0.25 in) diameter steel rod, resting on a rigid flat steel support. Proof loading shall be gradually applied without shock at the point of intersection of the specimen and the steel rod by means of a rigid square pressure plate having face dimensions of 100 mm (3.937 in) $\times$ 100 mm (3.937 in). The proof load to be applied by means of the pressure plate shall be either a gravitational force load of 102 kg (225 lb) or an equivalent mechanical force load. After a minimum time of not less than 30 s and with the proof loading continuously applied, the dielectric test outlined in 4.1.1 shall be conducted. The test voltage shall be applied between the heating cable conductors and the metallic covering, or where a metallic covering is not provided, between the conductors and the steel rod.

4.1.8 Impact test

The impact test shall be conducted on a sample that is positioned on a hardened rigid steel plate and the assembly conditioned for a minimum of 4 h at the manufacturer's minimum recommended installation temperature. After conditioning and while still at the minimum recommended installation temperature, a sample shall be subjected to the impact forces of a 5.08 cm (2 in) diameter cylindrical steel plunger with smoothly rounded edges, having a mass of 1.8 kg (4 lb) and allowed to free fall from a height of 76.2 cm (30 in), resulting in an impact force of 13.6 J (10 ft-lb). Then the impacted portion of the sample shall be immersed in tap water at room temperature, and the dielectric test outlined in 4.1.1 shall be conducted. For surface heating devices, both the heating region and cold leads shall be impacted. After testing, the sheath or dielectric insulation shall have no visible cracks when examined with normal vision.

4.1.9 Cold bend test

This test applies only to flexible heating devices that have a stated minimum bending radius of less than 30 cm (12 in). The apparatus used for the bend test shall be as represented in Figure 2. A sample of heating cable or cold lead shall be fixed in the apparatus as shown in Figure 2. With the test sample in position, the apparatus shall be placed in a refrigerated compartment and maintained at the minimum recommended installation temperature for a period of not less than 4 h. At the end of this period, and with the sample maintained at the minimum recommended installation temperature, the sample shall be bent through 90° around one of the bending mandrels, then bent through 180° in the opposite direction over the second bending mandrel and straightened to its original position. All the bending operations shall be carried out in the same plane. This cycle of operations shall be performed three times. For heating panels the heating region shall be bent around a mandrel equivalent to the manufacturer's minimum bending radius. When this has been completed, the sample shall be immersed in tap water at room temperature for 5 min, and then the dielectric test outlined in 4.1.1 shall be conducted.

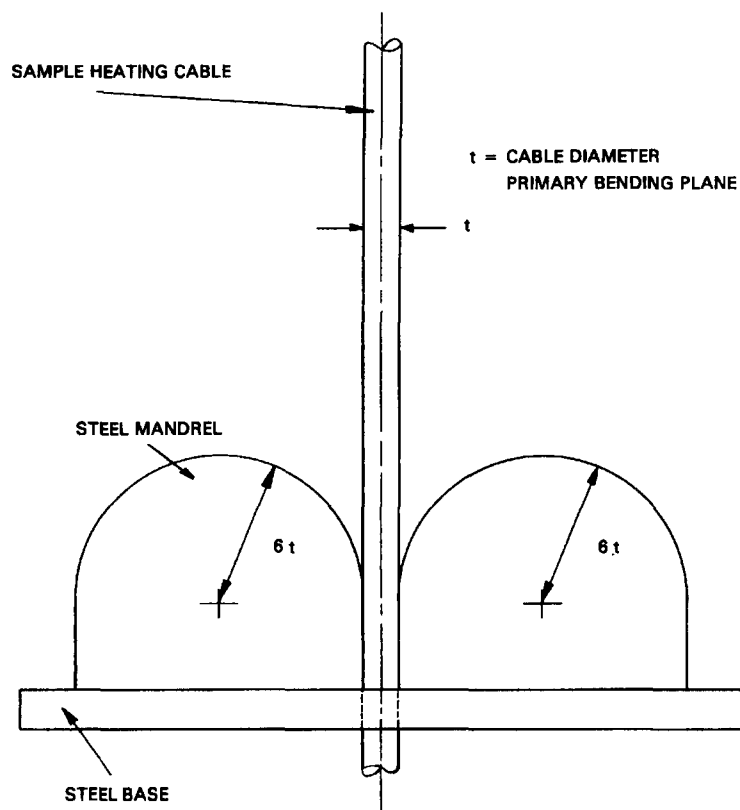


Figure 2—Cold bend test apparatus

4.1.10 Flammability test

A flammability test shall be performed on samples of surface heating devices or heating cables. The full range of sizes shall be capable of complying with the test. The test shall be conducted in a three-sided metal cabinet having dimensions of 30 cm (12 in) wide, 35 cm (14 in) deep, and 65 cm (25 in) high. The cabinet in which the test is conducted shall be in a draft-free room or chamber. A sample of heating device at least 46 cm (18 in) in length shall be supported in a vertical position. For surface heating units the sample width should be 7.62 cm (3 in). A gummed kraft paper indicator shall be wrapped once around the sample such that it projects 2 cm (0.75 in) from the sample. The paper indicator shall be positioned 25 cm (10 in) above the point at which the inner blue cone of the flame contacts the specimen. In addition, a layer of dry untreated surgical cotton not more than 0.6 cm (0.25 in) in depth shall be placed underneath the sample, such that the distance from the cotton to the point of the flame application is 23–24 cm (9–9.5 in).

A standard laboratory burner described in ASTM D 5025-94 shall be used for the test. The gas flame produced by the burner is to be calibrated as described in ASTM D 5207-91. The fuel shall be methane, propane, or natural gas, and shall be of a grade suitable for calibration to the ASTM D 5207-91 procedure. As shown in Figure 3, the flame shall be adjusted to a 13 cm (5 in) height with a 4.0 cm (1.56 in) inner blue cone. The burner shall be tilted to an angle of 20° from the vertical and the flame applied to the heating cable so that the tip of inner blue cone of the flame touches the specimen at a point 25 cm (10 in) below the kraft paper flame indicator and approximately 15 cm (6 in) from the bottom of the sample. For termination assemblies, the flame shall be set such that it will contact the material at the most vulnerable point. Clamps used to support the sample shall be above the paper indicator and at least 8 cm (3 in) below the point of flame application.

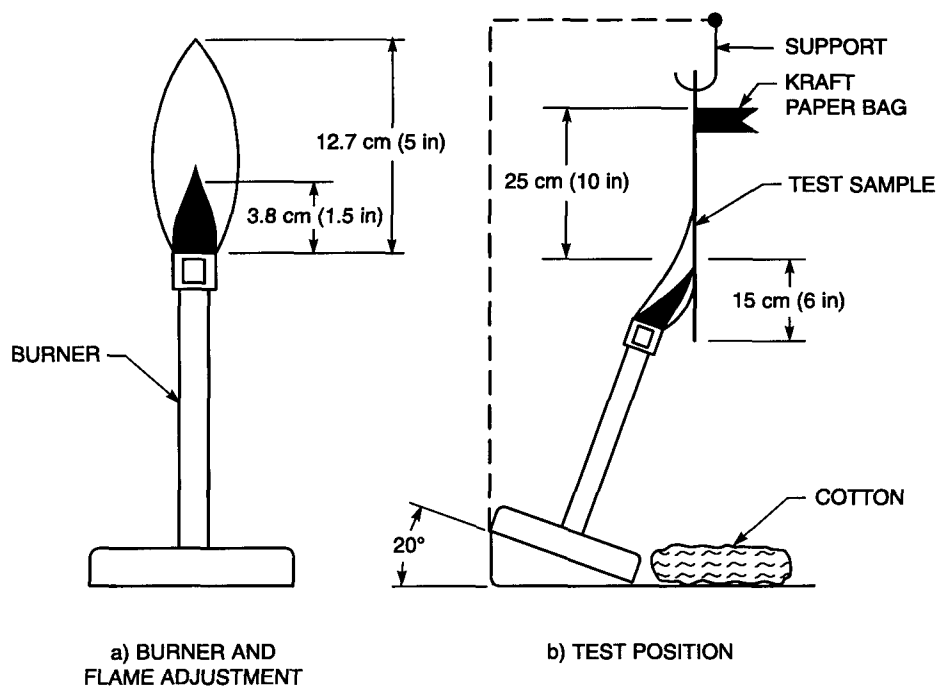


Figure 3—Flammability test

The flame shall be brought up to the heating device in such a manner that the vertical plane containing the major axis of the burner tube shall be at right angles to the sample. The flame shall be applied for 15 s, then removed for 15 s, until five such applications have been made.

The test results shall be considered satisfactory if the heating device does not support combustion for more than 1 min after the fifth application of the flame, does not burn more than 25% of the extended kraft paper, and does not ignite the cotton from burning falling particles.

4.1.11 Verification of rated output

The rated output of the heating cable or surface heating device shall be verified by one of the following three methods:

- Conductance*—The measured ac conductance or conductance per unit length, at a specified temperature, shall be within the manufacturer's declared tolerance.
- Resistance*—The measured dc resistance or resistance per unit length, at a specified temperature, shall be within the manufacturer's declared tolerance.
- Thermal*—For heating cables the thermal output shall be measured by installation of a single 3 m to 6 m (10 ft to 20 ft) sample of heating cable on a schedule 40 carbon steel pipe of 50.8 mm (2 in) diameter or greater, as shown in Figure 4. The cable shall be installed per the manufacturer's instructions. The test apparatus shall be completely covered with a fiber glass thermal insulation of 25.4 mm (1 in) or equivalent.

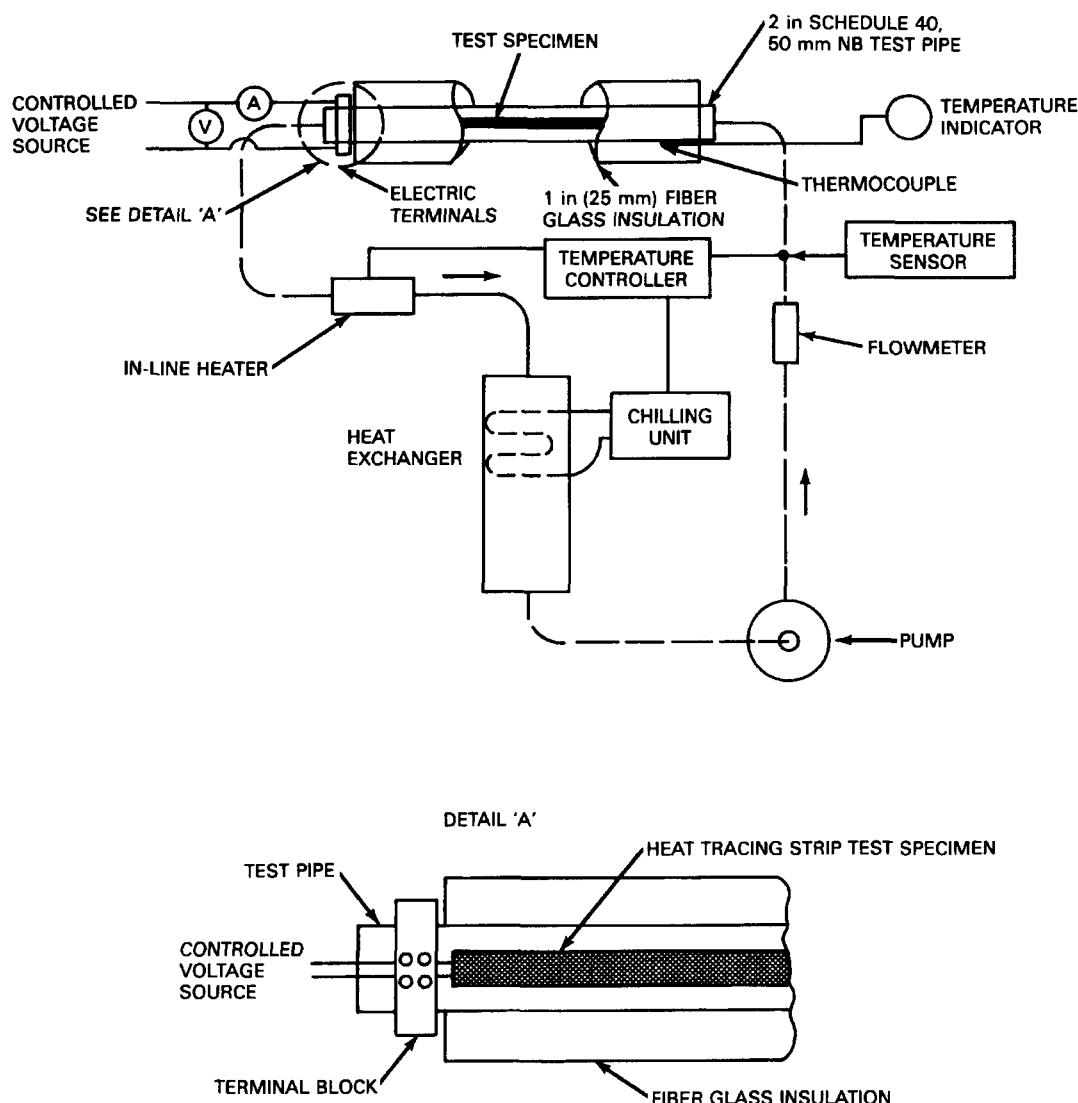


Figure 4—Verification of rated output

For surface heating devices, the test shall be conducted on a flat metal plate with rapid heating and cooling capability. Fiberglass thermal insulation, 2.54 cm (1 in) thick, shall be installed over the surface heating device.

A suitable heat-transfer fluid in the liquid phase shall be circulated through the pipe or metal plate fixture at a sufficient rate to establish turbulent flow corresponding to a Reynolds number greater than 2300. This will establish negligible temperature difference between the fluid and the pipe temperature. Sufficient means should be utilized to maintain constant temperature of the heat-transfer fluid. These parameters shall be verified by thermocouples placed at the entry and exit ends of the pipe. Flow velocity shall be sufficient so that the fluid temperature does not differ by more than 2 °C (3.6 °F) from end to end.

The thermal output of the heating device shall be measured at three pipe temperatures over the heater operating range. The heating device shall be powered at its rated voltage and allowed to attain equilibrium. The voltage, current, fluid temperature, and sample length shall be recorded at each test temperature. Three separate determinations shall be made on separate samples. The resulting values shall be within the manufacturer's declared tolerance.

4.1.12 Verification of start-up current

The start-up current of the heating device shall be measured as a function of the manufacturer's minimum designated ambient temperature. A sample of heating cable at least 1 m (3 ft) in length is installed per manufacturer's instructions on a minimum 50 mm (2 in) diameter fluid-filled steel pipe, solid rod, or for surface heating devices, a flat metal heat sink. The testing apparatus shall be completely covered with thermal insulation and conditioned at the test temperature for at least 4 h. The apparatus described in 4.1.11 c) can be used for this test. After the conditioning period, rated voltage shall be applied and the time/current characteristics shall be recorded from time zero to 300 s. The time current characteristic of any of the three samples shall not be more than the value declared by the manufacturer. The samples shall be in the upper 1/3 of the manufacturer's declared power output tolerances.

4.1.13 Verification of metallic covering conductivity

A metallic braid or sheath is required as part of the heating cable construction and shall cover at least 80% of the surface. For surface heating devices (panels) an integral metallic screen grid or covering on the exposed surface opposite the surface to be heated shall be incorporated into the construction. The resistance of at least 3 m (10 ft) length of heating cable shall be measured at room temperature using a four-wire resistance (Wheatstone bridge) method. A representative sample of a surface heating device shall be used. The resistance shall be equal to or less than the manufacturer's declared value.

4.2 Type test—Verification of sheath temperatures

Maximum sheath temperatures of heating devices must be determined to ensure the proper application of the heater. The maximum sheath temperature is dependent on the heater watt density, overall heat-transfer coefficient, and the runaway pipe/tank/tube bundle temperature. These factors are used by the manufacturer to determine the sheath temperatures of the heating device, as illustrated in 6.4.2, Equation 4. Subclause 6.5 defines the operational and environmental conditions for the test for each of the types of classifications. The certifying agency shall verify the maximum allowable watt density and sheath temperatures declared by the manufacturer.

One of the following two methods shall be used for determining heating device's sheath temperatures:

- a) A systems approach, in which the product is subjected to a test condition, where the manufacturer demonstrates the ability to design and predict sheath temperatures by conducting tests on specific installations
- b) A product classification approach, in which maximum sheath temperatures are generated in an artificial environment simulating worst-case conditions

4.2.1 Systems approach—Design verification method

This procedure is used to validate a manufacturer's design methodology and calculations. This procedure may be repeated with varied parameters, such as insulation type and thickness, to the satisfaction of the certifying agency.

For heating cables, the test apparatus as shown in Figure 5 shall consist of a 3 m (10 ft) horizontal run and 1.5 m (5 ft) vertical run of piping having a pipe size between 50 mm and 150 mm (2 in and 6 in) diameter. A flanged gate valve or equivalent (butterfly valve, globe valve, etc.) would be located in the center of the horizontal run. The vertical run should be so arranged that flanged pipe ends are in the center (refer to Figure 5). The heating cable shall be installed in a manner consistent with the manufacturer's installation instructions. Thermocouples shall be used to monitor the pipe and valve surface temperatures and cable sheath temperatures. The thermocouples should be located at anticipated hot spots at the discretion of the certifying agency. The piping system should be insulated with a minimum of 25 mm (1 in) thickness of thermal insulation and installed in accordance with the manufacturer's installation procedures. Pipe ends should be plugged and thermally insulated. For tubing bundles, the test apparatus shall consist of 4.5 m (15 ft) of traced tube bundle, with thermocouples located at the discretion of the certifying agency. The heating cable shall be powered at over-voltage conditions based on the area classification; see 6.5. System temperatures shall be allowed to stabilize and thermocouple readings recorded. The measured sheath temperatures shall not exceed the manufacturer's calculated values by more than 10 °C (18 °F).

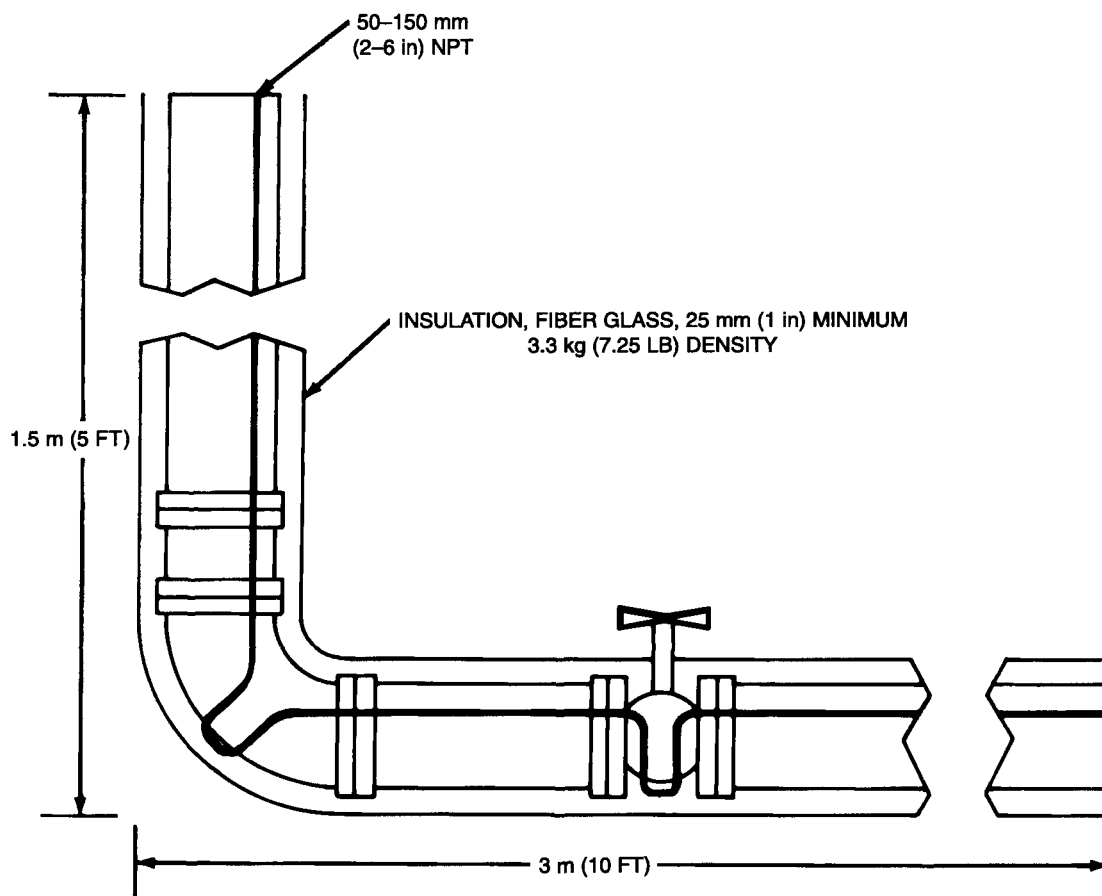


Figure 5—Verification of sheath temperature using system approach

For surface heaters, a representative section shall be applied to a 6 mm (0.25 in) steel plate in accordance with the manufacturer's installation instructions. The steel plate shall not extend more than 25 mm (1 in) from any edge of the surface heater. Thermocouples shall be used to monitor the temperature of the external surface of the heater. The thermocouples should be located at anticipated hot spots at the discretion of the certifying agency. The heated side of the plate shall be insulated with a minimum of 25 mm (1 in) of thermal insulation. The plate is then located in a stable room temperature environment in a vertical orientation. The surface heater shall be powered at over-voltage conditions based on the area classification according to 6.5. After stabilization, the thermocouple readings are recorded, including the local ambient temperature. The measured surface temperatures shall not exceed the manufacturer's calculated value by more than 10 °C (18 °F).

4.2.2 Product classification approach

A sample of heating cable at least 1.5 m (5 ft) in length is placed loosely coiled in a forced air circulation oven. For a surface heater, a representative section is placed horizontally in the oven. The sample shall be within the upper half of the heating device's thermal output tolerance. Representative thermocouples are used to monitor sample sheath temperatures and are placed 500 mm (20 in) from each end. One additional thermocouple is used to monitor oven ambient. The heating device shall be powered at over-voltage conditions based on the area classification; see 6.5. The oven ambient temperature is incrementally raised from room ambient in 15 °C (27 °F) increments. Sufficient time is permitted at each temperature for the oven ambient and heater sheath temperatures to stabilize and attain thermal equilibrium. Oven ambient and heater sheath temperatures are recorded at each successive level until the difference (ΔT) between the two approaches 5 °C (9 °F) or less. A curve is drawn from the test data, and a straight line is drawn tangent to the curve at 5 °C temperature difference point and extended to the X axis (oven temperature). The temperature read at this intercept is taken as the maximum sheath temperature, as shown in Figure 6.

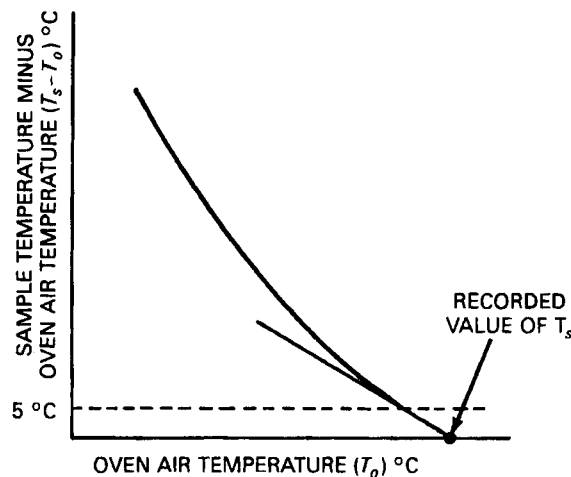


Figure 6—Maximum sheath temperature using product classification approach

4.3 Specific type test requirements for hazardous (classified) locations

Test values for certain of the type tests listed in 4.1 and 4.2 shall be adjusted for the different hazardous locations.

4.3.1 Class I, Division 1 locations

Heating cables and surface heating devices recommended for these areas shall be tested for severe chemical exposure, impact, and static mechanical loads. Additional type testing shall be required for system components. The following tests are intended to qualify heating devices for application in these hazardous (classified) areas and are required in addition to all the type tests described in 4.1.

4.3.1.1 Verification of sheath temperatures

The sheath temperature test described in 4.2 shall be conducted in accordance with design conditions detailed in 6.5, and the resultant sheath temperature shall not exceed 80% of the ignition temperature of the gas or vapor likely to be present.

4.3.1.2 Mechanical type tests

The deformation test as described in 4.1.7 shall be conducted at 204 kg (450 lb), two times the value specified in 4.1.7. The impact test as described in 4.1.8 shall be conducted retaining the same impact area, however, with an increased impact force of two times the specified value, 27.1 J (20 ft-lb).

4.3.1.3 Chemical exposure tests

The heating device shall be exposed (completely immersed except for the connections) to the following chemicals: acetone, ethyl acetate, isooctane, hexane, methanol, methyl ethyl ketone, methylene chloride, and toluene. The exposure duration shall be 24 h. The chemical shall be maintained at a temperature not less than 5 °C (9 °F) below the boiling point. Boiling points shall be obtained from NFPA 325-1994.

- a) A separate heater sample including any polymeric jacket shall be stressed by wrapping it six close turns around a mandrel having a radius equal to 12 times the diameter of the primary bending plane of the device, and shall be exposed (completely immersed except for the ends) to each of the above chemicals. The test sample shall be removed from the fluid, allowed to stabilize for at least 1 h, and then subjected to the dielectric test outlined in 4.1.1 with the sample (except for the exposed ends) immersed in tap water at room temperature. The test voltage shall be applied between the water and the metallic covering for heating device constructions with a polymeric jacket, or between the water and the heating device conductors for heater constructions without a polymeric jacket. No dielectric breakdown shall occur. Additionally, stressed samples shall have no visible cracks or other damage when examined. This test confirms the integrity of the heater jacket or sheath after chemical exposure.
- b) An additional set of unstressed samples shall be exposed to the same chemicals in a like manner. After the exposure, the test samples shall be removed from the fluid, allowed to stabilize for at least 1 h, and then subjected to the following tests:
 - 1) *Deformation*—The deformation test described in 4.1.7 shall be conducted on the heating device. Proof loads shall be two times the indicated value, 204 kg (450 lb).
 - 2) *Impact*—The impact test described in 4.1.8 shall be conducted, retaining the same impact areas. The impact force shall be two times the indicated value, 27.1 J (20 ft-lb).
 - 3) *Cold bend*—The cold bend test described in 4.1.9 shall be conducted.
 - 4) *Ground path integrity*—Ground path conductance shall be measured based on 4.1.13. After the chemical exposure, the continuous metallic sheath or braid shall have a conductivity equal to or greater than the manufacturer's declared value.

4.3.1.4 Ignition test

Components that affect the explosionproof characteristics of the equipment (heating device, seal fitting, gasket, etc.) shall be tested as an assembly with the heating device powered after exposure by immersion to the chemicals described in 4.3.1.3. Exposure temperatures and duration remain as specified in the referenced paragraph. A series of at least 10 ignition tests will be performed. These tests will use a representative gas for the group rating of the equipment, and varying mixtures as tabulated in the table below.

Division groups	Zone groups	Gas	Test mixture range percentage by volume in air
A	IIC	Acetylene	6.0–12.4
B	IIB+H ₂	Hydrogen	22.6–38.2
C	IIB	Ethylene	4.4–9.9
D	IIA	Propane	3.0–6.5

The equipment enclosure and a surrounding container shall be filled with the appropriate gas mixture. The internal gas mixture of the equipment enclosure will then be ignited and internal pressure reading taken. The test results shall be considered satisfactory if the following occurs:

- There is no ignition of the gas mixture in the surrounding container during any test.
- There is no visible permanent deformation of any part that is critical to the explosionproof characteristics of the equipment.

4.3.1.5 Hydrostatic test

A hydrostatic test shall be performed using the same components from the ignition test to verify a margin of safety over and above the maximum recorded ignition test pressure. This test pressure shall be four times the maximum recorded ignition pressure. There shall be no rupture or displacement of the components that may affect the explosion proof characteristics of the equipment.

4.3.2 Class II and III, Division 1

Heating cables and surface heating devices for these hazardous (classified) locations shall meet additional impact, static mechanical load, and dust exclusion tests. The following tests are intended to qualify heating devices and components for use in these hazardous (classified) areas and are required in addition to the type tests described in 4.1.

4.3.2.1 Verification of sheath temperatures

The sheath temperature test described in 4.2 shall be conducted at design conditions defined in 6.5, and the resultant sheath temperature shall not exceed 80% of the ignition temperature of the dust likely to be present. The maximum temperature for organic dusts is 165 °C (329 °F).

4.3.2.2 Mechanical type tests

The deformation test as described in 4.1.7 shall be conducted at 204 kg (450 lb), two times the value specified in 4.1.7. The impact test as described in 4.1.8 shall be conducted retaining the same impact area, however, with an increased impact force of two times the specified value, 27.1 J (20 ft-lb).

4.3.2.3 Dust exclusion test

Heat-Tracing system components shall be assembled complete with 0.8 m (31.5 in) of terminated heating cable/device. The assembly shall be suspended in a circulating dust atmosphere of 200 mesh talc while connected to a vacuum pump adjusted to draw 200 mm (7.9 in) of water. The test shall be conducted at an air extraction rate of 4.9 volumes per hour over an 8 h test period. The test chamber is maintained at 20 °C (68 °F) during the test. At the conclusion, excess dust shall be removed from exterior surfaces. The enclosure shall be opened and examined for dust. No dust shall be inside the enclosure.

4.3.3 Class I, Division 2 locations

Tests as defined in 4.1 shall be used. Sheath temperature tests shall be as defined in 4.2, with operational conditions as described in 6.5.

4.3.4 Class II and III, Division 2 locations

Tests as defined in 4.1 and 4.2 shall be used. Sheath temperature tests shall be as defined in 4.2, with operational conditions as described in 6.5. System component must also pass dust exclusion tests as described in 4.3.2.3.

4.3.5 Class I, Zone 1 locations

Heating cables and surface heating devices required for these areas shall be tested for severe chemical exposure, impact, and static mechanical loads. Additional type testing is also required for system components. The following tests are intended to qualify heating devices for application in these hazardous (classified) areas and are required in addition to all the type tests described in 4.1.

4.3.5.1 Verification of sheath temperatures

The sheath temperature test described in 4.2 shall be conducted per design conditions detailed in 6.5, and the resultant sheath temperature shall not exceed 80% of the ignition temperature of the gas or vapor likely to be present.

4.3.5.2 Mechanical type tests

The deformation test as described in 4.1.7 shall be conducted at 204 kg (450 lb), two times the value specified in 4.1.7. The impact test as described in 4.1.8 shall be conducted retaining the same impact area, however, with an increased impact force of two times the specified value, 27.1 J (20 ft-lb).

4.3.5.3 Chemical exposure tests

Chemical exposure tests shall be conducted per 4.3.1.3.

4.3.5.4 Ignition test

Components that affect the explosion proof characteristics of the equipment (heating device, seal fitting, gasket, etc.) shall be tested as an assembly with the heating device powered after exposure by immersion to the chemicals described in 4.3.1.3. Exposure temperatures and duration remain as specified in the referenced paragraph. A series of ignition tests as noted in Tables 1 and 2 shall be performed to separately address the issues of pressure and propagation (nontransmission). These tests will use a representative gas for the group rating of the equipment, and varying mixtures as tabulated in Tables 1 and 2.

Table 1—Ignition tests to address pressures*

Zone groups	Gas	Test mixture range percentage by volume in air	Series of ignition tests
IIC	Acetylene	$14.0 \pm 0.5\%$	5
	Hydrogen	$31.0 \pm 1.0\%$	5
IIB+H ₂	Hydrogen	$31.0 \pm 1.0\%$	5
IIB	Ethylene	$8.0 \pm 0.5\%$	3
IIA	Propane	$4.6 \pm 0.3\%$	3

*Adopted from IEC 79-1 (1990) [B10].

The equipment enclosure and a surrounding container shall be filled with the appropriate gas mixture. The internal gas mixture of the equipment enclosure shall then be ignited and internal pressure reading taken during the ignition tests that address pressure. The test results shall be considered satisfactory if the following occurs:

- There is no ignition of the gas mixture in the surrounding container during any test.
- There is no visible permanent deformation of any part that is critical to the flameproof characteristics of the equipment.

Table 2—Ignition tests to address propagation*

Zone groups	Gas	Test mixture range percentage by volume in air	Series of ignition tests
IIC	Acetylene	$7.5 \pm 1.0\%$	5
	Hydrogen	$27.0 \pm 1.0\%$	5
IIB+H ₂	Hydrogen	$27.0 \pm 1.0\%$	5
IIB	Hydrogen	$37.0 \pm 0.5\%$	5
IIA	Hydrogen	$55.0 \pm 0.3\%$	5

*Adopted from IEC 79-1 (1990) [B10].

4.3.5.5 Hydrostatic test

A hydrostatic test shall be performed using the same components from the ignition test to verify a margin of safety over and above the maximum recorded ignition test pressure. This test pressure shall be four times the maximum recorded ignition pressure. There shall be no rupture or displacement of the components that may affect the flameproof characteristics of the equipment.

4.3.6 Class I, Zone 2 locations

Tests as defined in 4.1 shall be used. Sheath temperature tests shall be as defined in 4.2, with operational conditions as described in 6.5.