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IEEE Recommended Practice for Electrical Impedance, Induction, and Skin Effect Heating of Pipelines and Vessels

Sponsor

IEEE Industry Applications Society
of the
Petroleum and Chemical Industry Committee

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Abstract: Recommended practices are provided for the design, installation, testing, operation, and maintenance of impedance, induction, and skin-effect heating systems. Thermal insulation and control and monitoring are addressed. General considerations for heating systems are discussed, covering selection criteria, design guidelines and considerations, power systems, receiving and storage, installation, testing, operations, and maintenance. These aspects are then discussed for each of the above types of systems, along with special considerations particular to each. These recommended practices are intended to apply to the use of these heating systems in general industry.

Keywords: heating systems, impedance heating, induction heating, process heating, skin-effect heating, thermal insulation

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Introduction

(This introduction is not a part of IEEE 844-2000, IEEE Recommended Practice for Electrical Impedance, Induction, and Skin Effect Heating of Pipelines and Vessels.)

The types of heating systems covered by this draft recommended practice have been used for a number of years in the petrochemical industry. They were recognized for the first time in the 1981 issue of the National Electrical Code® ANSI/NFPA 70-1990.

Electrical heating of pipelines and vessels in the petrochemical industry is a growing portion of total heating requirements because of its advantages in temperature control and the rise of energy costs. This recommended practice is a companion document and supplements IEEE Std 515-1997, IEEE Standard for the Testing, Design, Installation, and Maintenance of Electrical Resistance Heat Tracing for Industrial Applications. While this recommended practice may be used with IEEE Std 515-1997 to select the type of electrical heating to be used, it is a stand-alone document for the types of heating it covers.

Since electric heating systems are interrelated with electric power, control, and alarm systems, other standards, some of which are listed in Clause 2, should be referred to when using this recommended practice. The recommendations here are not intended to supersede any current standards or recommended practices, and sound engineering judgment should always be used when applying this or any other standard.

This recommended practice correlates petrochemical industry practices; it is not intended to be a design guide or an exhaustive procedure manual. It may be used to evaluate different heating systems and suppliers of those systems for suitability and performance. The appendixes are included for information only; they are not part of this recommended practice.

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IEEE Recommended Practice for Electrical Impedance, Induction, and Skin Effect Heating of Pipelines and Vessels

1. Overview

This recommended practice is divided into 11 clauses. Clause 1 provides the scope. Clause 2 lists references to other standards that are useful in applying this recommended practice. Clause 3 provides definitions that are either not found in other standards or have been modified for use with this recommended practice. Clause 4 establishes requirement for general product testing. Clause 5 provides information on thermal insulation systems that is useful in applying this recommended practice. Clause 6 provides information on the control and monitoring of heating systems covered in this recommended practice. Clause 7 provides general information for the selection, design, installation, and maintenance of heating systems covered by this recommended practice. Clause 8 provides specific information related to impedance heating. Clause 9 provides specific information related to induction heating of pipelines and vessels. Clause 10 provides specific information related to induction susceptor heating furnaces within a vessel. Clause 11 provides specific information related to skin-effect heating.

This recommended practice also contains Annexes. Annex A provides bibliographical references. Annex B provides heat-loss formulas and example calculations. Annex C provides vessel heat loss considerations. Annex D provides heat-up considerations. Annex E provides calculations for determining the thickness of thermal insulation cement. Annex F provides the theory of induction heating. Annex G provides a sample specification for a susceptor heating system.

1.1 Scope

This document provides recommended practices for the design, installation, testing, operation, and maintenance of the following types of electrical heating systems on pipes and vessels for use in general industry: impedance heating systems, induction heating systems, induction susceptor heating furnaces within a vessel, and skin-effect heating systems.

1.1.1 Limits

These recommended practices, when used with other recognized codes and standards, are intended to cover each heating system in its entirety, including system design, specification, installation, operation, testing, and maintenance of the following:

- a) Heating systems
- b) Thermal insulation systems
- c) Pipeline or vessel electrical isolation systems
- d) Electric power supply systems
- e) Electric grounding systems
- f) Control and monitoring systems

1.2 Purpose

1.2.1 System design

Design information, selection parameters, and data in this document are not intended to provide a complete design of these heating systems. They should be helpful guides when the user is performing the following tasks:

- a) Selecting the optimum heating system
- b) Establishing design criteria and constraints for the heated pipeline or vessel to assure system compatibility
- c) Preparing specifications for heating systems to obtain quotations on equivalent systems
- d) Developing information on installation, operation, testing, and maintenance of these heating systems

1.2.2 User guidance

This document is intended to aid the user in specifying, installing, operating, testing, and maintaining heating systems that will

- a) Maintain design temperature of contained material
- b) Provide electrical, thermal, and mechanical durability and reliability
- c) Minimize hazards to the user or the surroundings

1.3 Product certification

Users of this recommended practice are advised to consider the desirability of third party certification of products conforming with this standard, based on testing and continued surveillance, which may be coupled with assessment of a supplier's quality systems.

2. References

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

AEIC CS6-96, AIEC Specification for Ethylene Propylene Rubber Insulated Shielded Power Cables Rated 5 kV through 69 kV (6th edition).¹

NFPA 70-1999, National Electrical Code[®], (NEC[®]).²

ASTM D1868-93 (1998), Standard Test Method for Detection and Measurement of Partial Discharge (Corona) Pulses in Evaluation of Insulation Systems.³

IEEE Std 141-1993, IEEE Recommended Practice for Electric Power Distribution for Industrial Plants (Red Book).⁴

IEEE Std 400-1991, IEEE Guide for Making High-Direct-Voltage Tests on Power Cable Systems in the Field.

IEEE Std 1202-1991 (R1996), IEEE Standard for Flame Testing of Cables for use in Cable Tray in Industrial and Commercial Occupancies.

UL 1581-1997, Reference Standard for Wires, Cables, and Flexible Cords.⁵

3. Definitions

For the purposes of this recommended practice, the following terms and definitions apply.

3.1 ambient temperature: The environmental temperature surrounding the object under consideration. For objects enclosed in thermal insulation, it is the temperature external to the thermal insulation.

3.2 ampere turns: The product of the number of turns and the ac amperes flowing in an induction heating coil.

3.3 certification: Attesting that unit has demonstrated ability to perform in accordance with pre-established criteria.

3.4 certifying agency: Organization, office, or individual that validates that equipment meets tests and standards.

3.5 contaminant: Any solid or liquid material which is not an intended ingredient.

3.6 Curie temperature: The temperature at which the magnetic properties of a substance change from ferromagnetic to paramagnetic.

3.7 dead leg: A portion of a piping system, without flow, used to simulate the overall system conditions for control sensing.

¹AEIC publications are available from the Association of Edison Illuminating Companies, 600 N. 18th Street, P. O. Box 2641, Birmingham, AL 35291-0992, USA (<http://www.aeic.org/>). AEIC publications are also available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112-5704, USA (<http://global.ihs.com/>).

²ANSI publications are available from the Sales Department, American National Standards Institute, 11 West 42nd Street, 13th Floor, New York, NY 10036, USA (<http://www.ansi.org/>).

³ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (<http://www.astm.org/>).

⁴IEEE publications are available from the Institute of Electrical and Electronics Engineers, 445 Hoes Lane, P.O. Box 1331, Piscataway, NJ 08855-1331, USA (<http://standards.ieee.org/>).

⁵UL standards are available from Global Engineering Documents, 15 Inverness Way East, Englewood, Colorado 80112, USA (<http://global.ihs.com/>).

3.8 depth of current penetration: The thickness of a layer extending inward from the surface of a conductor that has the same resistance to dc as the conductor as a whole has to ac of a given frequency.

3.9 eddy current: Current that circulates in a metallic material as a result of electromotive forces induced by a variation of magnetic flux.

3.10 effective flux penetration (P): The distance into a pipeline or a vessel wall that the value of current induced by the magnetic field at the surface would have to penetrate in order to generate the same heat as generated by the actual induced current distribution in the wall.

3.11 extra flexible: Cable or conductor with a minimum flexibility of ASTM Class D stranding.

3.12 ferromagnetic envelope: A pipe, tube, angle, or channel of ferromagnetic material used as a raceway to enclose a skin-effect cable.

3.13 ferromagnetic material: A material that, in general, exhibits hysteresis phenomena and whose permeability is dependent on the magnetizing force.

3.14 ground detector: An instrument or equipment used for indicating the presence of a ground on an ungrounded system.

3.15 ground leak/fault detector: A device that detects an abnormally low electrical resistance from an isolated electrical circuit to ground.

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

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

3.18 hot zone: The parts of an induction susceptor heating system that operate at significantly elevated temperatures. This includes the susceptor and load.

3.19 impedance heating: An electric heating system where the object to be heated generates heat as a result of an ac current passing through it.

3.20 induction coil: A helical electrical conductor of one or more electrical turns, usually of a shape conforming to that of the outside of the vessel, pipeline, or susceptor, in which time varying magnetic flux is produced by an alternating flow of electrical current.

3.21 induction heating: The generation of heat in any conducting material by means of magnetic flux-induced currents.

3.22 magnetic flux (ϕ): A condition in a medium produced by a magnetomotive force such that when altered in magnitude, a voltage is induced in an electric circuit linked with the flux.

3.23 magnetic flux density (β): Flux per unit area through an element of area normal to the direction of flux.

3.24 magnetic flux leakage: That portion of the total magnetic flux in a circuit that does not intercept the material that contains the magnetic flux doing the heating.

3.25 magnetic hysteresis: The property of a magnetic material to convert electric energy to heat by virtue of the fact that the magnetic induction for a given magnetizing force depends upon the previous conditions of magnetization.

3.26 magnetic yokes (shunts): Magnetic lamination stacks arranged vertically between the vessel wall and induction coil. These provide a low reluctance return path to the magnetic flux generated by and external to the induction coil to prevent stray flux from heating vessel wall or exterior supports.

3.27 maintain temperature: Specified temperature of the fluid or process material that the heating system is designed to hold at equilibrium under specified design conditions. *Syn:* **maintenance temperature.**

3.28 maximum exposure temperature: The highest temperature to which an object may be exposed continuously.

3.29 pass through: An electrical conductor assembly that is designed to carry the coil current through a vessel wall, while keeping the conductors electrically insulated and preventing excessive induction heating of the vessel port.

3.30 permeability (μ): Ratio of the magnetic flux density to the corresponding magnetizing force.

3.31 pipeline: A length of pipe, including pumps, valves, flanges, control devices, strainers, or similar equipment for conveying fluids.

3.32 power factor: The ratio of the circuit power (watts) to the circuit volt amperes.

3.33 power port: An opening through which the pass-through conductors enter the vessel. The area around the conductors is made of an electrical insulating material designed to seal and withstand the differential pressure between the inside and outside of the vessel.

3.34 runaway pipeline (vessel) temperature: The highest equilibrium temperature on the pipeline or the vessel that can occur when the heating system is continuously energized in the maximum ambient temperature.

3.35 saturation flux density (β_s): The maximum possible magnetic flux density in a material.

3.36 skin-effect heating: An electric heating system where a conductor inside a ferromagnetic envelope material generates heat via I^2R losses in the conductor and ferromagnetic material.

3.37 soft start: The ability of a controlling device to apply power to a load upon energization in a proportional manner, irrespective of values of the controlling signals.

3.38 susceptor: An energy absorbing device generally used to transfer heat to another load.

3.39 susceptor heating containment vessel: A closed container designed to contain an induction coil in a protective atmosphere. The atmosphere can be a vacuum, an inert gas, or a process gas selected to react with the product within the susceptor. The vessel must be designed to safely withstand the pressure differential between the inside and the outside and any heat load conducted or radiated to the vessel walls.

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

3.41 thin wall susceptor: A susceptor in which the calculated depth of penetration is greater than the susceptor wall thickness.

3.42 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.

3.43 vessel: A container such as a barrel, a drum, or a tank for holding fluids or other material.

3.44 water cooled leads: Electrical power conductors that are cooled by circulating water through a nonconductive hose which contains the conductors.

3.45 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.

3.46 zoning: A division of circuits to minimize different conditions in any one circuit, so the temperature at the location of a sensor is typical for the complete circuit.

4. General product testing

All tests shall be conducted at room temperature between 10 °C and 40 °C unless otherwise noted. Type test sample selection shall include all material constructions and shall be based on a worst-case size criterion where applicable.

Products may be deemed to have met a specific requirement of this recommended practice, based on documented alternate testing of the product which meets or exceeds the stated requirement, when agreed between the submitter and certifying agency.

4.1 General product type tests for impedance heating power cable

The following type tests are intended to qualify impedance heating power cables for the application within the scope of the standard.

4.1.1 Sunlight resistance test

A resistance to sunlight test shall be performed on samples of impedance heating power cable in accordance with Clause 1200 of UL 1581-1997.

4.1.2 Flammability test

A vertical flame test shall be performed on samples of impedance heating power cable in accordance with IEEE Standard 1202-1991.

4.1.3 Impact resistance test

An impact resistance test shall be performed on samples of impedance heating power cable in accordance with Clause 593 of UL 1581-1997.

4.2 General product type tests for induction heating

The following type tests are intended to qualify induction heating power cables for the application within the scope of this recommended practice.

4.2.1 Sunlight resistance test

A resistance to sunlight test shall be performed on samples of induction heating power cable in accordance with Clause 1200 of UL 1581-1997.

4.2.2 Flammability test

A vertical flame test shall be performed on samples of induction heating power cable in accordance with IEEE Standard 1202-1991.

4.2.3 Impact resistance test

An impact resistance test shall be performed on samples of induction heating power cable in accordance with Clause 593 of UL 1581-1997.

4.3 General product type tests for susceptor heating furnaces within a vessel

This clause is intentionally left blank for future use.

4.4 Product testing for skin-effect heating systems

4.4.1 Type tests for skin-effect heating systems

The following type tests are intended to qualify skin-effect cables for the application within the scope of this recommended practice.

4.4.1.1 Dielectric test

A 3 m sample of skin-effect cable with the exception of the ends shall be immersed in water for a minimum period of 6 h. An ac test voltage, as indicated in Table 1, shall be applied between the skin-effect cable and tap water at room temperature (dielectric volume resistivity typically 50 000 $\Omega\cdot\text{cm}$).

Table 1—Skin-effect dielectric test

Skin effect cable rating (Vac)	AC hi-pot voltage (kV)
0–600	5.5
601–2000	7.0
2001–3000	11.0
3001–5000	13.0

The test voltage shall be applied at a rate of rise neither less than 100 V/s nor more than 200 V/s and maintained for 5 min. The test voltage waveform shall be essentially sinusoidal, with a frequency of 45–65 Hz. No dielectric breakdown shall occur.

4.4.1.2 Elevated temperature exposure dielectric test

A 3 m sample of skin-effect cable shall be placed in a forced-circulation air oven. The oven shall be heated to, and maintained at, a temperature of $25\text{ }^{\circ}\text{C} \pm 5\text{ }^{\circ}\text{C}$ above the highest exposure temperature declared by the manufacturer for a period of 21 days. The sample shall be removed from the air oven and cooled to room temperature. The sample shall be wound six close turns around a mandrel having a radius equal to twelve times the diameter of the primary bending plane or thickness of the conductor. While still on the mandrel the sample, except for the ends where the conductor is exposed, shall be submerged in tap water at $10\text{--}25\text{ }^{\circ}\text{C}$ for 5 min. While still in the tap water, the dielectric test in 4.4.1.1 shall be performed. Upon completion of the test, the sample shall have no visible cracks when examined with normal vision.

4.4.1.3 Cold bend test

The apparatus used for the bend test shall be as represented in Figure 1. A 3 m sample of skin-effect cable 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 a test temperature value $20\text{ }^{\circ}\text{C}$ below the manufacturer's 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 test 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 sequence of operations shall be performed three times. When this has been completed, the sample shall be immersed in tap water at room temperature for 5 min, and then the dielectric test in 4.4.1.1 shall be conducted on the sample.

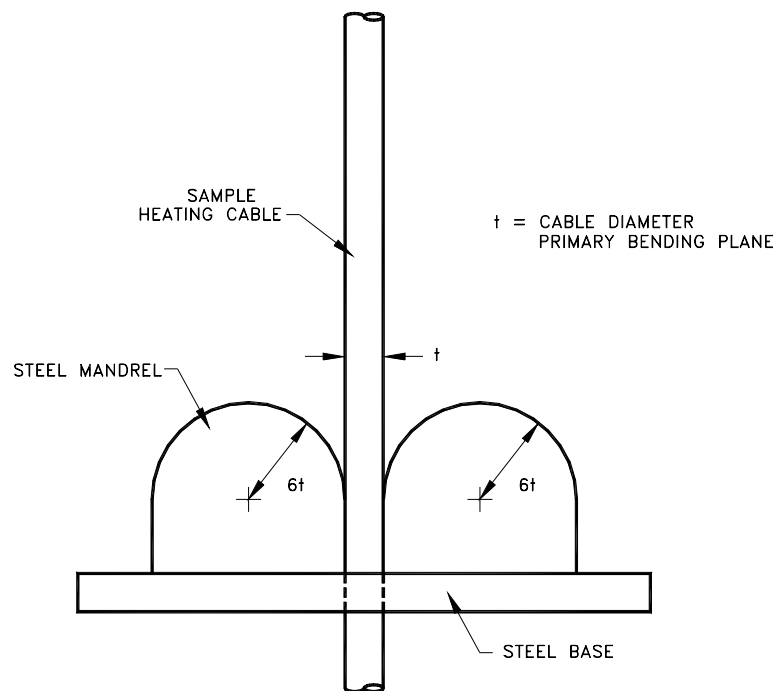


Figure 1—Cold bend test apparatus

4.4.1.4 Abrasion resistance test

This test shall be applied to three representative samples of the largest and the smallest skin-effect cables.

4.4.1.4.1 Apparatus

The apparatus, as illustrated in Figure 2, shall consist of a machine designed to hold a specimen of finished cable in a horizontal position and under tension. The specimen shall be mounted using a sash chain at each end, one being fastened to a rigid support while the other is passed over a pulley free to rotate about its fixed axis and subjected to tension by means of a weight (W).

The distance between the rigidly supported end and the axis of the pulley shall be 1.5 m. A wooden block approximately 65 mm thick and having a 89 mm radius curved surface on the underside shall be attached to a pivoted arm. The pivot point of the arm shall be 178 mm from the curved surface of the block at the center of the 1.5 m span.

A reciprocating shaft connected to the arm shall oscillate the skin-effect cable through an arc of approximately 100° , at the rate of 20 ± 1 cycles/min, in the same direction as the axis of the test specimen. By means of a ratchet device, the block automatically shall move in a transverse direction of approximately 2 mm/min. The machine shall also be provided with a counting device to record the number of cycles.

The position of the block in relation to the surface of the specimen to be abraded shall be such that the specimen is depressed from its original horizontal position a distance of 25 mm when the block is at the center point of its swing. With the block in that position, it shall be in contact with the cable at approximately the midpoint of the length of the specimen.

The abrading medium, which shall consist of medium grade emery cloth (80 grit), shall be held in close contact with the curved surface of the block by mechanical means. The emery cloth shall be refreshed each time the arm reaches the end of its transverse travel.

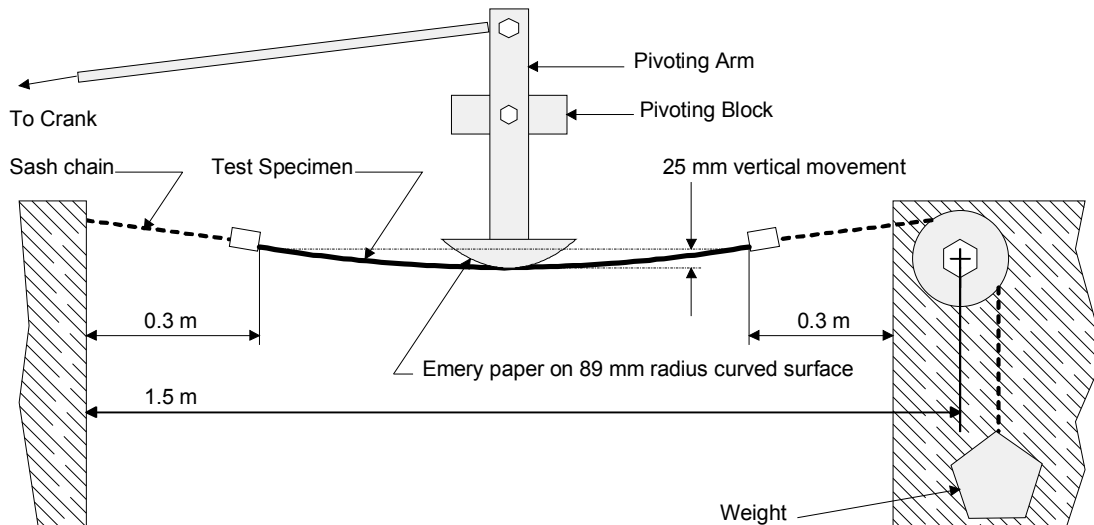


Figure 2—Abrasion resistance test apparatus

4.4.1.4.2 Procedure

Six specimens of finished cable, each of 0.9 m in length, shall be placed in the test fixture abrasion machine one at a time and abraded for a calculated number of cycles. The number of cycles shall be calculated in accordance with 4.4.1.4.3. Fresh emery cloth shall be used for each specimen.

4.4.1.4.3 Calculation of weight and number of cycles

Calculation of the number of test cycles N_t is determined by the following equation:

$$N_t = FLC/W_t \quad (1)$$

where

- N_t is the number of test cycles required for each test (a cycle being one complete motion of the pivoting arm from the start position to the end of travel and back to the start position).
- F is the manufacturer's stated maximum pulling force (kg, newton).
- L is the manufacturer's stated maximum unspliced length (m).
- C is the constant 0.2 kg (0.0204 N).
- W_t is the test weight used in the apparatus for the actual tests which can be chosen to be any value which can be practically utilized in the test fixture abrasion machine (kg).

Example calculation of the number of test cycles: Based on an example cable where the manufacturer's stated maximum pulling force (F) is 45.4 kg (445 N), and the maximum stated unspliced length (L) is 457 m, the test weight (W_t) used in the test apparatus is 13.6 kg, and the calculation is as follows:

$$N_t = 45.4 \times 457 \times 0.2 / 13.6 \text{ kg} = 305 \text{ cycles}$$

4.4.1.4.4 Proof test

After abrading for the required number of cycles, each sample shall be tested using the ac dielectric test in 4.4.1.1.

4.4.1.5 Heat distortion test

A 200 mm sample of skin-effect cable, along with the weight/frame test fixture, shall be placed in a forced-circulation air oven. The oven shall be heated to, and maintained at, a test temperature which is 25 °C above the insulation rating.

A 9.5 mm diameter bearing surface having a weight of 300 g at oven temperature shall be placed onto the skin-effect cable for a period of 1 h. The skin-effect cable insulation shall be measured using a dial micrometer before and after the 1 h application of the weight. The insulated cable specimen shall be measured as follows: The diameter (D), in millimeters, over the insulation at a marked position shall be measured using a dial micrometer. The diameter (d), in millimeters, of the conductor, shall also be measured, and the thickness (T) of the insulation shall be calculated as follows:

$$T = (D - d)/2 \quad (2)$$

The distortion characteristic shall be determined as follows:

$$\text{Distortion (\%)} = \frac{T_{\text{initial}} - T_{\text{final}}}{T_{\text{initial}}} \times 100 \quad (3)$$

The heat distortion of the skin-effect cable measured shall not exceed 30%.

4.4.1.6 Corona discharge rating test (for skin-effect cables rated at 2001 vac or higher)

Nonshielded skin-effect cables rated 2001 V or higher shall be subjected to one of the following two corona discharge tests.

4.4.1.6.1 Corona discharge rating test

A minimum of three 1.5 m samples are each mounted separately in 13 mm or larger steel tubes (tube size is to be representative for the conductor size and the application). Test voltage is applied between the skin-effect cable conductor and the heat tube while at room temperature. The voltage is raised in 200 V increments holding each level for 1 min until the corona inception voltage [the inception voltage (CIV) being defined as the voltage at which more than 5 pC of discharge occurs] is attained as detected by a partial discharge meter, measurement circuit (circuit No. 3 in ASTM D1868-93), and an oscilloscope. The CIV is recorded. The voltage level is then increased in 200 V to 250 V steps to a voltage level equal to 20% greater than the minimum CEV level expected but not exceeding the dielectric voltage test levels defined in 4.4.1.1. Subsequently, the voltage is lowered in 200 to 250 V increments with a pause of 1 min at each level until the corona extinguishes [the extinguish point (CEV) being defined as the voltage at which the discharge ceases or drops below 5 pC]. The CEV level is recorded. The procedure is then repeated at higher skin-effect cable temperature levels in order to obtain corona ratings up to the maximum conductor temperature rating. Where various insulation thicknesses are to be implemented, two or more test thicknesses are required to validate calculation methodology of design thicknesses and ratings for a given material. All corona discharge ratings shall be based on the primary insulation thickness only and shall not consider any sacrificial scuff jacket thickness. Skin effect cable voltage ratings shall not exceed 80% of the average CEV value of the samples and shall not be more than the lowest measured CEV value of any one sample.

4.4.1.6.2 Optional U-bend corona withstand test

This test may be used in lieu of the corona discharge rating test of 4.4.1.6.1 for voltage ratings between 2001 V and 5000 V. Four sample lengths of finished skin-effect cable, each at least 1.5 m long are to be prepared. Two of the samples are to be bent at their midpoints for 180° around a mandrel with a diameter equal to six times the cable outside diameter. The sides (legs) of each U-bend specimen is to be supported separately with its bend down and the legs of the U extending upward in a vertical plane. The center of each bend is to rest on a flat, horizontal metal plate that is earth grounded. A 48–62 Hz essentially sinusoidal RMS test potential of 13 kV magnitude is to be applied between the conductor in each test specimen and the grounded metal plate for a minimum of 6 h. The cable is acceptable if neither of the first specimens break down electrically and there is no visible cracking, erosion, or tracking of the outside surface. A change in color or glossiness or other appearance is not cause for rejection. If either of the first two specimens break down or show cracking, erosion, or tracking, the test is to be repeated on the remaining two specimens. The cable is not acceptable if either of the two additional specimens break down or show cracking, erosion, or tracking.

4.4.1.7 Skin Effect Splice Pullbox Type Test

The skin-effect pullboxes shall be designed and tested to meet or exceed the requirements of either the NEMA 4 rating in accordance with NEMA-250-1999 [B26]⁶ or IP-56 in accordance with IEC 60529:1991 [B14].

4.4.1.8 Splice Resistance to Moisture Test

A sample of skin-effect cable at least 3 m in length that includes a factory- or field-assembled splice connection 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 above the maximum exposure temperature declared by the manufacturer for a period of 21 days. The aged sample shall then be placed in a water flow and drain apparatus as shown in Figure 3. The rate of the water flow shall be regulated to completely cover the skin-effect cable and the splice termination, at a minimum of every 5 min. Activation of the water flow solenoid and heating device shall be controlled by a cam switch or equivalent means. The timing sequences shall be such that the skin-effect cable shall be energized for 30 s at its maximum room temperature declared current rating after the

⁶The numbers in brackets correspond to those of the bibliography in Annex A.

water has been drained. The test shall be continued for a period of 24 h. At the end of the test period, the dielectric test in 4.4.1.1 shall be performed on the skin-effect cable/splice sample.

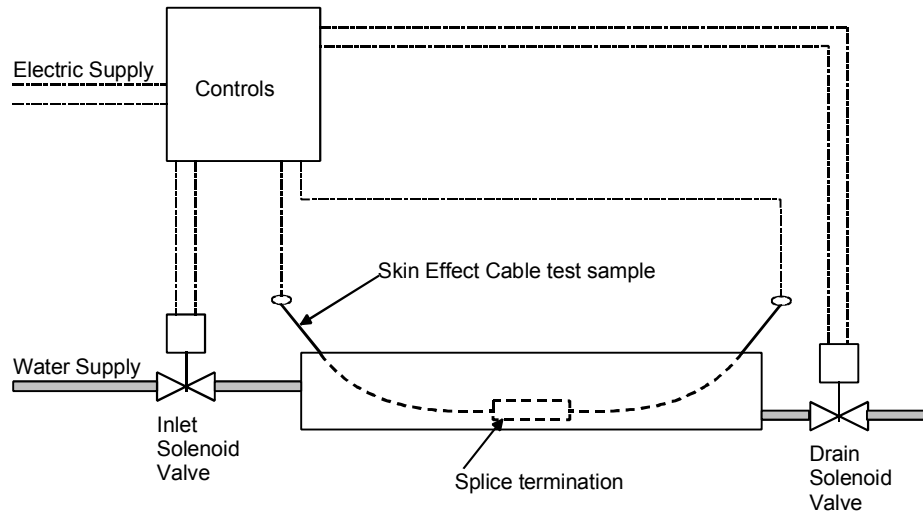


Figure 3—Skin effect cable—Splice resistance test apparatus

4.4.1.9 Conductor resistance test

The resistance of the skin-effect cable shall be verified. The measured dc resistance or resistance per unit length at a specified temperature shall be within the manufacturer's declared tolerance.

4.4.1.10 Power output and system impedance verification

The manufacturer shall demonstrate the ability to predict power output and system impedance by conducting tests on representative installations and comparing the results to design predictions. The apparatus described in 4.4.1.10.1 shall be used by applying either the test method in 4.4.1.10.2 or 4.4.1.10.3.

4.4.1.10.1 Apparatus

A test skin-effect system of at least 5 m in length shall be built in accordance with the manufacturer's instructions. The test skin-effect system shall be installed on a 50 mm (2 in NPS) steel pipe or larger, and shall be insulated with a minimum of 38 mm thick thermal insulation of the manufacturer's choosing. The selection of the heat tube and skin-effect cable combinations shall be agreed upon by the system manufacturer and the certifying agency and shall be representative of typical system installations. The test system shall include, at minimum, typical power and end termination boxes, and optionally, may include a pull/splice box. Low mass laboratory type temperature sensors shall be used to monitor the pipe, heat tube, and skin-effect cable sheath temperatures at anticipated hot spot areas to the discretion of the certifying agency. A power supply transformer with multiple taps capable of supplying the maximum rated current for the selected heat tube/skin-effect cable combination shall be provided.

4.4.1.10.2 Stagnation method

Operating voltage, current, power factor, heat tube length, heat tube temperature, skin-effect cable sheath temperature, and process pipe temperature shall be recorded at three power levels and three process pipe temperature levels (attained by varying the insulation heat loss or taking measurements during heat up) which cover the normal design power/maintenance temperature range of the heat tube/skin-effect cable. The measured skin-effect system power output and impedance per unit length shall be within 10% of the calculated/predicted impedance at the measured heat tube temperature.

4.4.1.10.3 Flow method

The apparatus described in 4.4.1.10.1 shall be used. The process pipe shall be connected into a temperature controlled circulating fluid system. Operating voltage, current, power factor, heat tube length, heat tube temperature, skin-effect cable sheath temperature, and process pipe temperature shall be recorded at three power levels and at three different pipe temperatures, which cover the normal design power range/maintenance temperatures of the heat tube/skin-effect cable. The measured skin-effect system power output and impedance per foot shall be within 10% of the calculated/predicted impedance at the measured heat tube temperature.

4.4.1.11 Verification of sheath temperatures

The manufacturer shall demonstrate the ability to predict skin-effect cable sheath temperatures by conducting tests on representative installations and comparing the results to design predictions. The apparatus described in 4.4.1.10.1 shall be used. Operating voltage, current, power factor, heat tube length, heat tube temperature, skin-effect cable sheath temperature, and process pipe temperature shall be recorded at three different power levels. The measured skin-effect cable sheath temperature shall not exceed the manufacturer's calculated/predicted value.

4.4.2 Routine testing

These tests shall be carried out by the manufacturer during or after production to verify conformance to the manufacturer's specifications.

4.4.2.1 Resistance test

The measured dc resistance per unit length of the skin-effect cable at a specified temperature shall be within the manufacturer's declared tolerance.

4.4.2.2 Dielectric tests

The tests consists of voltage tests on each length of a completed cable that would be used as the conductor in a skin-effect heating system. Cables rated 0–2000 V shall be submitted either to a dielectric spark test (ac or dc) or to an ac dielectric test. Cables rated 2001–5000 V shall be submitted either to an ac dielectric test, to a dc dielectric test, or to an impulse spark test at $1.414 \times$ ac test value as determined by 4.4.2.2.2.

4.4.2.2.1 Dielectric spark test

During the manufacturing each unit length of a cable shall withstand, without failure, a spark test in accordance with Table 2 below and Clause 900 of UL 1581-1997.

Table 2—Dielectric spark test

Skin effect cable nominal voltage (Vac)	AC spark test voltage (KV)	DC spark test voltage (kV)
0–600	10	16
601–2000	15	22.5

4.4.2.2.2 AC dielectric test

The completed cable, with the exception of the ends, shall be immersed in water at room temperature for at least 6 h. An ac test voltage as indicated in Table 3 shall be applied between the conductor and the water. The test voltage waveform shall be basically sinusoidal with a frequency between 45 Hz and 65 Hz. The

initial test voltage shall be equal to the nominal voltage rating of the cable. The duration of the test shall be 5 min. The test method shall be in accordance with Clause 820 of UL 1581-1997.

Table 3—AC dielectric test

Skin effect cable nominal voltage (Vac)	AC voltage test (KV)
0–600	5.5
601–2000	7.0
2001–3000	11.0
3001–5000	13.0

4.4.2.2.3 DC dielectric test

The completed cable, with the exception of the ends, shall be immersed in water at room temperature for at least 6 h. The initial test voltage shall be equal to 3.0 times the nominal ac voltage rating of the cable. A dc test voltage as indicated in Table 4 shall be applied between the conductor and the water. The duration of the test shall be 5 min. The test method shall be in accordance with Clause 820 of UL 1581-1997.

Table 4—DC dielectric test

Skin effect cable nominal voltage (Vac)	DC voltage test (kV)
0–600	15.0
601–2000	22.5
2001–3000	25.0
3001–5000	30.0

4.4.2.3 Gels, agglomerates, contaminants, and voids test (for skin-effect cable rated 2001 vac or higher)

A minimum of one skin-effect cable sample of 50 mm in length from each production run (with additional samples being taken at 3048 m intervals) shall be cut helically or some other convenient manner to produce thin samples of the insulation. Wafers (or the turns of the helix) shall be cut with a thickness of approximately 0.635 mm producing approximately 80 wafers. The entire area of twenty consecutive wafers (or equivalent helical turns) shall be examined with a 15 power magnification microscope with reflected light. The examined samples can not have 1) any voids larger than 0.102 mm, 2) any contaminants larger than 0.254 mm, or 3) gels and agglomerates larger than 0.254 mm in the greatest dimension. The test method shall be in accordance with AEIC CS6-96.

5. Thermal insulation

The primary function of thermal insulation is to reduce the rate of heat transfer from or to a surface that is operating at a temperature other than ambient. Thermal insulation is applied to piping systems for personnel protection and energy conservation. This reduction of energy loss can reduce operating expenses, improve system performance, and increase system output capability. Conversely, improperly applied or maintained thermal insulation may render an electric heating system totally ineffective.

Prior to any heat loss analysis for an electrically heated pipe or vessel, a review of the selection of the insulation is recommended. The principal areas for consideration are as follows:

- a) Selection of insulation material
- b) Selection of insulation thickness
- c) Selection of insulation size

5.1 Selection of insulation material

The important aspects to be considered when selecting an insulation material are as follows:

- a) Thermal characteristics
- b) Mechanical properties
- c) Chemical compatibility
- d) Moisture resistance
- e) Personnel safety characteristics
- f) Fire resistance
- g) Cost

Some common insulation materials available are as follows:

- a) Calcium silicate
- b) Fiberglass
- c) Polyurethane
- d) Mineral fiber
- e) Polyisocyanurate
- f) Expanded (perlite) silica
- g) Cellular glass
- h) Elastomeric foam

5.2 Selection of weather barrier

Proper operation of an electrically heated system depends upon the insulation being dry. Electrical heating systems normally have insufficient heat output to dry out wet insulation.

Some insulation materials, even removed from the piping and force-dried, never regain their initial properties after once being wet.

Piping insulation may be weather protected with either metal jacketing or a polymeric system. Smooth metal jacketing should be formed with modified S longitudinal joints. The circumferential end joints should be sealed with closure bands and supplied with sealant on the outer edge or overlapped; see Figure 4.

Metal jacketing should be overlapped such that the longitudinal joints are as shown in Figure 4. These joints should be oriented such that they shed water.

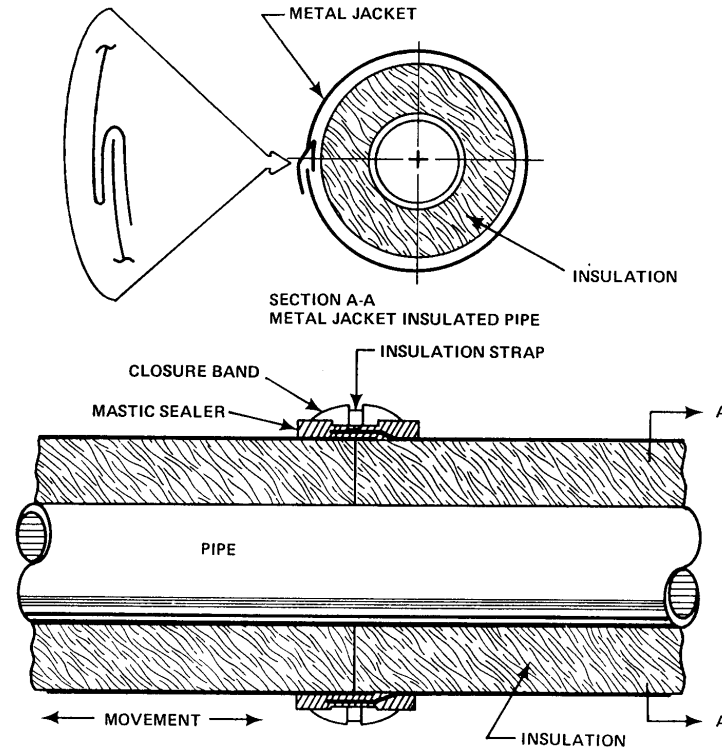


Figure 4—Thermal insulation metal weather barrier installation

Factory-applied thermal insulation and jacketing of a preinsulated piping system can have many configurations. Generally, the techniques used in applying the jacketing, whether in straight sections or spiral wound, are not repeatable under field conditions. The manufacturer's instructions should be followed in supporting the pipeline and sealing field joints to prevent intrusion of moisture.

Jacketing that is not overlapped or otherwise closed without sealant is not effective as a barrier to moisture. A single unsealed joint can allow a considerable amount of water to leak into the insulation.

The type of weather barrier used should be based on a consideration of the following:

- Effectiveness in excluding moisture
- Corrosive nature of chemicals in the area
- Fire protection requirements
- Cost
- Resistance to ultraviolet radiation
- Durability to mechanical abuse

5.3 Selection of insulation thickness

An economic consideration of the insulation will weigh the initial costs of materials and installation against the energy saved over the life of the insulation. Methods for analyzing the most economic thicknesses are

outlined in Energy Conservation Paper No. 46 [B11] and Turner and Malloy [B32]. In all cases, thermal insulation thickness should also be sized to provide personnel protection.

5.4 Special consideration of thermal insulation

5.4.1 Uniform heat loss

In most piping systems minor local temperature deviations are acceptable, since many fluids are not temperature sensitive to the point where they will affect product quality. In cases where extreme temperature sensitivity does necessitate close temperature control, it is imperative that the thermal insulation maintain uniform heat loss throughout the piping system. The entire heating system may be rendered ineffective if thermal insulation is not properly applied.

This problem is further amplified as temperatures are elevated. Most insulations suitable for use on high-temperature lines are mechanically rigid. Insulation should be cut to fit with minimum gaps. A ceramic wool for the filling of voids and irregularities at joints and heat sinks is preferred over insulating cements, which tend to become brittle after being cured and have poor insulating qualities. Normal thermal cycling of the process will, in time, cause the insulating cements to crack, exposing bare pipes and creating heat losses that are not normally anticipated.

Insulation covers for valves, flanges, pipe supports, and other irregularly shaped objects should be molded for the particular configuration or fabricated from block or several segments of the same material used for adjacent straight piping.

The use of custom-prefabricated removable insulation and weather barriers should also be considered for areas of high maintenance. Where insulation with a thermal conductivity different from that being applied to the pipe is used to totally insulate an irregular surface, the thickness of the insulation must be adjusted to compensate for differences in thermal conductivity and surface area. However, a custom fitting of the equipment with the same type of material is preferred. This is very important when dealing with impedance, induction, or skin-effect types of heating systems, since it is often difficult, if not impossible, to provide additional local heat to individual valves, flanges, pipe supports, or other heat sinks to compensate for the heat lost through irregular or exposed surfaces. An example illustrating this point is presented in Annex E.

5.4.2 Composite insulation systems

Insulation systems may be composed of two layers of the same type of insulation that are applied in such a manner to stagger the joints. The staggering of the joints radially and longitudinally would allow the insulation to flex with the thermal cycling of the pipeline. An alternative would be to construct the insulation with the inner layer having a temperature rating that withstands high temperature, and the outer layer having better insulating or moisture characteristics with a lower temperature rating.

These systems are superior to normal, single-layer insulations in terms of heat loss and deterioration with time. They may not be acceptable for every application because of spacing, cost, or other considerations. Other systems are available and should be examined on a case-by-case basis.

On very-high-temperature systems, designing to prevent radiation heat loss is critical, and insulation experts should be consulted.

5.4.3 Preinsulated pipe systems

A typical preinsulated piping system consists of a carrier pipe, insulation, and outer jacket. The preinsulated piping system is supplied from a single source of responsibility, fabricated and insulated in a controlled environment. Most commercially available insulation and piping materials can be incorporated into the

piping system. The use of preinsulated piping systems can offer the user and designer many advantages over conventionally insulated piping systems.

- a) The heat tube of a skin-effect type heat trace system can be welded to the carrier or containment pipe with a controlled process, for a permanent and reliable heat path. Prefabricated fittings are supplied with the heat tube formed to the fitting, saving a field process.
- b) The manufacturer of the preinsulated piping system can implement and monitor quality control procedures for the preparation and installation of the heat tube. This can provide a smooth bore, free of burrs, to ensure a successful cable installation.
- c) The insulation is applied to the carrier or containment pipe with a controlled process, reducing the risk of field error.
- d) The thermal insulation jacket provided with a prefabricated system minimizes seams found in a conventionally insulated system, making the preinsulated system durable and watertight.
- e) Most preinsulated piping systems can be mechanically supported from the outer jacket, with a saddle placed between the insulation jacket and support. This eliminates the additional heat loss caused by conventional pipe supports.

When using preinsulated piping, the following are special considerations:

- a) Preinsulated piping must be used on new systems only. It cannot be applied to existing piping.
- b) Prefabricated, preinsulated systems may require detailed engineering design, prior to the fabrication of the system to allow proper supporting, anchoring, and allowance for expansion.
- c) Installation should comply with all requirements of the preinsulated piping supplier. Substitutions should not be made without the agreement of the supplier.
- d) The usage of the line should be considered prior to choosing the insulation materials.

5.4.4 Penetrations of the insulation

When necessary to penetrate the weather barrier and insulation for process instruments, pipetaps, or other reasons, the penetrations should be sealed with a flexible, UV resistant caulk and oriented such that they shed water due to rain, spills, sprinkler system operations, or routine hosing. Bottom penetrations are desirable. Consideration should be given to the effect of relative motion between the pipe and the weather barrier due to thermal expansion.

5.4.5 Maximum temperatures

The maximum surface temperature of the pipe or the vessel should be considered to the extent that none of the component ratings are exceeded in the application. This includes electrical insulation and isolation, thermal insulation, pipe wall material, process material, and control instrumentation. The maximum surface temperature of the thermal insulation should also be considered for personnel protection. Typically, the maximum surface temperature of the thermal insulation or weather barrier should not exceed 60 °C for personnel protection.

5.4.6 Wet insulation

Thermal insulations become ineffective when water is present. Hygroscopic insulations, such as calcium silicate, should be avoided for electric heating applications, unless special considerations are taken to exclude moisture.

5.5 Determination of energy losses

To determine actual energy losses for a given set of conditions, a complete insulation specification, including the thermal conductivity of the insulant at several mean temperatures, the type of weather barrier specified, insulation size and thickness, desired pipe maintenance temperature, and the minimum ambient temperature and wind conditions, is required.

Given these parameters, the heat loss may be evaluated by the use of Equation B.1 in Annex B. An example of such an evaluation is given in Annex B.

Equation B.1 models heat loss for an ideal system under controlled conditions. Heat losses in a typical installation will differ due to variations in installation techniques, components, and system deterioration. It is sound engineering judgment to add a safety factor to the calculated heat losses when sizing the heating system. This safety-factor approach is typical not only for Equation B.1, but for subsequent heat-loss equations referred to in this recommended practice.

5.6 Special considerations of energy loss

5.6.1 Heat-up considerations

It may be necessary to specify that the heating system be capable of raising the temperature of a static product to fluid flow temperature within a certain time period. The heating requirements may be evaluated by the use of Equation D.1 in Annex D. An example of such an evaluation is given in Annex D.

5.7 Thermal insulation system maintenance

The maintenance of thermal insulation systems is essential for lowest cost operation and for reliability. The reliability of an electric heating system is as dependent upon the thermal insulation system as upon the electric power system. A thermal insulation system is a sound investment; good maintenance protects that investment.

5.7.1 Maintenance of insulation

Maintenance of thermal insulation is needed, especially as follows:

- a) The repair or replacement of damaged or soaked insulation caused by abuse, corrosion, leaks, or weathering.
- b) The repair or replacement of damaged insulation resulting from access to valves, pumps, or other equipment. In all cases, if the thermal insulation is wet, it must be removed and replaced.

One of the most common problems with maintenance is that, when repairs to equipment necessitate the removal of thermal insulation, the insulation is generally torn off without regard to its reuse. When valves, fittings, and other equipment are insulated with preformed covers, they should be removed carefully so they can be reinstalled in their original configuration. When repairs are being made, attention should be given to the adjacent insulation so as not to damage it inadvertently. A temporary weather barrier should also be used to protect the insulation from rain, hosing, or spills. In many cases, it is advantageous to install a permanent weather barrier on the ends of insulation adjacent to sections that will be removed frequently for maintenance.

5.7.2 Maintenance of the weather barrier

The primary reason for the failure of a thermal insulation system is the failure of the weather barrier to exclude moisture. Weather barrier failures are attributable to the following:

- a) Spillage of liquids
- b) Corrosion
- c) Pipeline leakage
- d) Gaps or unsealed joints
- e) Hot projections through the insulation
- f) Cracks caused by thermal expansion
- g) Mechanical abuse
- h) Foot traffic

Minimization of corrosion, spills, and leaks should be an operating goal. The problems they cause to unsealed insulation are significant. Gaps and unsealed joints can be located by inspection during construction. Cracks developing after prolonged operation, due to thermal expansion, indicate the need for an expansion joint in the insulation system. Cracks on smooth protrusions may be eliminated by the use of metal flashing and sealants fitted flush along the protrusion, while irregular objects will require repeated resealing.

In areas of high maintenance, foot traffic, or mechanical abuse, the weather barrier may have to be of additional strength, or an additional sheet of metal covering may need to be installed over the existing weather barrier to provide sufficient protection.

6. Control and monitoring

6.1 Control types

6.1.1 On-off controls

On-off is the simplest, least expensive form of control. It can be accomplished manually or automatically from an external signal, usually temperature activated. Contactors are usually used for service switching because of their simplicity and ability to control large amounts of power repetitively. Contactors should be sized for continuous load and inrush currents on cold load starts. Mechanical and contact life considerations may require a larger size contactor than is indicated by the electric load. The temperature control band is a compromise between accuracy of control, limitations on the number of operations of the contactor, and system design, so that the control range is usually broader than with other types of control. Contactors have moving parts, draw arcs when breaking circuits, are noisier, and require more maintenance than solid-state controllers. Use of mercury contactors alleviates noise and life problems. Enclosures must be suitable for the environment. It is critical with on-off control that the heating system match the service voltage available.

6.1.2 Analog (proportional) control

Analog control devices match the output power to the needs of the heating system and provide a stable load on the electrical distribution system as long as the heating requirements remain constant. They require a continuous signal whose level varies with measured temperature at the control point. Depending on the accuracy of the sensor and controller, they can control temperature very closely. These devices have no

moving parts, are relatively maintenance free, and have a long life provided they are properly installed and electrically protected. They do not mechanically open the circuit, so a switch and contactor, or a shunt-trip circuit breaker, should be provided in a series with the controller for overtemperature protection and circuit isolation. The following are commonly used analog control devices for heating applications.

6.1.2.1 Saturable core reactors

These devices can vary output voltage from approximately 10% to 100%, in proportion to the current in a dc control winding. The dc source can be controlled to provide soft-start capabilities. Reactors are constructed similarly to transformers and have an inherent ability to withstand voltage and current surges and overloads. Losses are dependent on coil and core construction, but generally are similar to losses in a transformer of equal size. Operation in the lower control range will result in a low system power factor. They are large, heavy, and expensive when compared to silicon-controlled rectifiers (SCRs).

6.1.2.2 Phase-angle-fired SCRs

These devices can continually vary output voltage from 0% to 100% by turning on for a varying portion of each half-cycle. The firing circuit is controlled to vary the firing time and can be equipped with a soft-start option to limit inrush to inductive loads. A current limit circuit is available to limit current to match the load and for control of cold start currents on variable resistance heaters. They require both voltage surge and thermal energy (I^2t) protection because of limited dielectric and thermal capabilities.

The chopping action of the SCR imposes harmonics on the electric system, which can be a problem when this type of load is a large percentage of the total system load. When phase control is adjusted for low output voltage, the distribution system power factor will be low. Meters that will read rms values of nonsinusoidal waves should be used. The most likely mode of failure is full on. There is usually a 1–2% loss in power in the control package. These devices must be packaged to suit the environment.

NOTE—Zero-fired (burst-fired) SCRs are not recommended.

6.2 Zoning and sensor location

To heat and control pipelines or vessels properly, consideration must be given to establishing heating zones that can be separately controlled. Many factors must be taken into consideration when establishing zones and locating sensors to properly control the zone.

6.2.1 Ambient conditions

For any single heating zone, the ambient conditions should be nearly uniform or the temperature differentials resulting from different ambient conditions should be acceptable. The complete zone should be either outdoors or indoors. Ambient temperatures and wind and sun loading conditions should be comparable in all portions of the zone.

6.2.2 Physical conditions

Pipelines or vessels that are to be in a single zone should be of equal size or have uniform heat loss. Consideration should be given to the chimney effect on sloped or vertical pipe runs, which tends to raise the temperature at the top because of convection.

6.2.3 Process Conditions

Required temperatures should be uniform throughout the zone. Flow conditions should be similar in all pipelines heated in a single zone. Varying fluid levels in vessels should be given consideration.

6.2.4 Temperature control sensor location

6.2.4.1 Ambient sensing

Ambient sensing may provide acceptable control to maintain a minimum temperature, such as for freeze protection. The sensor should be located where ambient conditions are typical and should be protected from direct sunlight.

6.2.4.2 Pipe or vessel sensing

The pipeline or vessel temperature sensor should be located so that response is typical for the complete zone. To maintain a minimum temperature, the sensor should be located on the coldest pipeline, at the bottom of vertical runs, in the coldest ambient, and in nonflowing lines. The sensor should be a minimum of 1 m from in-line heat sources or heat sinks. For skin-effect systems, the sensor should be located to avoid any direct temperature effect from the ferromagnetic envelope. If flow patterns are unpredictable, consideration should be given to locating the sensor on a dead leg (a segment of process piping that is not in the flow pattern). Overtemperature must be considered in applying these recommendations.

6.3 Types of sensors

Temperature sensor characteristics are shown in Table 5.

Table 5—Temperature sensor characteristics

Sensor type	Thermostat	Thermocouple	Thermistor	RTD
Signal	On-Off	Millivolt	Resistance	Resistance
Accuracy	Fair	Good	Very Good	Excellent
Response	Fair	Excellent	Very Good	Good
Interchangeability	Good	Very good	Good	Very good
Stability	Fair	Good	Very Good	Excellent
Range	Broad	Broad	Narrow	Broad

NOTE— Table characteristics are for sensors, and users should be aware that system control may be affected by the type of controller used with the sensor.

6.3.1 Thermostats

A thermostat is a combined sensor and on-off controller. The bimetal or fluid-filled system senses temperature changes and switches contacts. The sensor may be inside a thermostat housing or extended by a capillary tube for remote sensing. Enclosure and materials should be suitable for the environment. Thermostats should be inspected, calibrated, and mechanically operated on a scheduled basis.

6.3.2 Thermocouple

Thermocouples sense temperature and generate a millivolt signal, proportional to the temperature (ANSI MC96.1-1982 [B1]).

6.3.3 Thermistor

Thermistors sense temperature and change resistance very rapidly in the temperature control range. The change of resistance can be either positive or negative with an increase of temperature (EIA 309-1965 [B9]).

6.3.4 Resistance temperature detector (RTD)

Change of resistance of an RTD is uniform over a broad temperature range. Resistance increases as temperature increases. To improve accuracy, three leads are used to compensate for the lead-wire loop resistance and changes in lead resistance with a change in ambient temperature.

6.4 Wiring considerations

Electrical noise on signal wiring is a common cause of problems with some temperature control systems.

Consideration should be given to spacing sensor wiring away from power wiring; using twisted, shielded, or twisted/shielded cable; and using separate ferromagnetic raceways for sensor wiring. It is recommended that the cable shield be grounded at the instrument only.

6.5 Special control considerations

All heating systems covered in this recommended practice can be designed to heat the system rapidly. The sensors and controllers used should be able to respond quickly to temperature excursions to prevent temperature overruns.

Backup temperature control should be applied to prevent overtemperature in case of control failure. For this backup protection, an entirely separate system is recommended, including sensors, controllers, and power interrupting devices such as a shunt-trip circuit breaker or a magnetic contactor. This is especially important when saturable core reactors or SCRs are the primary control device, or when the heater is located in a hazardous (classified) location where the runaway temperature may exceed 80% of the lowest ignition temperature of the flammables in the area.

6.6 Control specifications

Each respective clause of this recommended practice details specifications required for the type of heating system used. The heating system vendor will normally recommend control and monitoring component specifications to meet the required heating system performance. General specifications for control and monitoring should include the following:

6.6.1 Controller location

Environmental conditions, such as maximum and minimum ambient temperature, indoor or outdoor location, routine hosing, solar heating, corrosives, and classification of the area with a description of hazardous substances, should be considered.

6.6.2 Accessibility

Control and monitoring equipment can be floor- or wall-mounted, have front or back access, and have a wiring entrance at the top, the bottom, or the side.

6.6.3 Electrical

Consideration should be given to available supply voltages and capacity interlocks; local or remote operation and indication; type of indicators desired (lights, meters, alarms, etc.); and quantity, type, and location of additional temperature monitoring.

6.6.4 Remote monitoring

Controllers that can be monitored and tested for proper operation from a remote location, such as a control room, should be considered when there are a large number of electrically heated pipelines or vessels dispersed over a large area.

7. Heating system—General

7.1 Introduction

These heating systems are composed of many components. Failure of any component to be designed, installed, or maintained as specified can result in failure of the system to function properly. To obtain a successful installation of any of these systems requires coordination and cooperation among piping, insulation, electrical, and support designers, purchasers, fabricators, and erectors, at all stages of a project.

7.2 Categories

Heating systems covered in this recommended practice can be divided into five categories.

7.2.1 Solidification prevention

Systems may be used to prevent the fluid in a line or a vessel from solidifying. Many materials handled in industry require this protection. These include water, aqueous solutions, heavy fuel oil, pitch, asphalt, metals, sulfur, and other chemicals. The heating system compensates for the heat losses from the pipeline in order to maintain the temperature of the contents above the solidification point.

7.2.2 Viscosity maintenance

Systems may be used to maintain viscosity of a fluid in a pipeline or a vessel. Viscous materials are generally heated to achieve optimum pump efficiency and pipeline sizes. Usually these materials are preheated to a temperature that provides the desired viscosity and pumped to their destination through heated pipelines designed to maintain that temperature.

7.2.3 Process heating

Systems may be used to maintain the temperature of fluids when process parameters require it. Systems may also be used to raise the temperature of process fluids flowing in the pipeline or the vessel, but they will require increased heat input capacity.

7.2.4 Condensation prevention

Systems may be used to prevent gaseous materials from condensing. Some gases will condense at low temperature and require heating to maintain their gaseous state during transportation. If pressure is reduced, increased heat input capacity may be required.

7.2.5 Remelting solidified fluids

Systems may be used to remelt solidified fluids. Some heating applications do not supply heat during pumping, but only supply heat to remelt line contents and bring them up to temperature prior to pumping. A typical example is an infrequently used loading or unloading line.

7.3 Selection criteria

This recommended practice covers only electrical impedance, induction, and skin-effect heating systems.

All three of these methods result in electrical currents flowing in the wall of the pipeline, the vessel, or the ferromagnetic envelope attached to the pipeline or the vessel. Impedance and induction heating require that the pipeline or the vessel itself be metallic. Skin effect heating requires that the envelope attached to the pipeline or the vessel be ferromagnetic material.

7.3.1 Impedance heating systems

Impedance heating systems introduce low-voltage ac to a section of the pipeline or the vessel to be heated and return the current through a cable. The wall of the current-carrying pipeline or vessel becomes the heating element. The return cable that completes the circuit, when it is laid parallel and adjacent to the pipeline or the vessel wall, creates a proximity effect. The skin effect and hysteresis losses especially enhance heating for ferromagnetic materials. Reasons for selecting impedance heating systems are detailed in Clause 8 of this recommended practice. Table 6 lists the limitations and advantages of impedance heating.

7.3.2 Induction heating systems

Induction heating, as used for pipeline or vessel heating, involves the use of electrically conductive coils encircling and electrically isolated from the pipeline or the vessel. Alternating voltage is applied to the coils, generating a rapidly changing magnetic field that induces hysteresis and eddy-current losses in the pipeline or the vessel walls. Reasons for selecting induction heating systems are detailed in Clause 9 of this recommended practice. Table 6 lists the limitations and advantages of induction heating.

7.3.3 Skin-effect heating systems

In skin-effect heating systems, the heat is generated in a small ferromagnetic envelope, containing the power supply conductor, attached to the pipeline or the vessel. Reasons for selecting skin-effect heating systems are detailed in Clause 11 of this recommended practice. Table 6 lists the limitations and advantages of skin-effect heating.

7.4 Design guidelines and considerations

After establishing which lines in a project will require heating, establishment of certain design parameters is required to evaluate the available systems. These are described in 7.4.1 through 7.4.5.

7.4.1 Material characteristics

Characteristics of materials in a pipeline must be known. These include density, specific heat, heat of vaporization, heat of fusion, thermal and electrical conductivity, and pour point.

7.4.2 Temperature requirements

Temperature requirements must be determined. These include process temperature to be maintained, minimum/maximum process temperature allowed, and minimum/maximum design ambient temperature conditions. If heat up of material is required, the time available to heat a cooled line to process temperature, initial and final product temperature desired, flow rate and direction, and whether operation of the pipeline is continuous or intermittent should be established.

7.4.3 Piping information

Piping information should include length of piping, diameter, material, schedule, insulation material, weather barrier material, insulation thickness and thermal conductivity, and maximum allowable pipe temperature.

7.4.4 Installation information

Installation information should include location of piping, indoor or outdoor, above or below ground, type of pipe joints, method of pipe support, location of water table (if below ground), design wind velocity, and hazardous classification and corrosives in the environment for location of heating system, power supply, and control equipment.

Table 6—General characteristics of induction, impedance, and skin-effect heating systems

Parameters	Induction heating	Impedance heating	Skin effect heating
Uniformity of heating	Fair	Excellent	Very good
System efficiency	Fair	Good	Excellent
System power factor	Poor	Moderate	High
Usual application	Short pipelines or vessels	Moderate pipelines	Moderate to long pipelines or vessels
Maximum maintenance temperatures	>649 °C	>649 °C	>260 °C
Hazardous areas	Yes	Yes	Yes
Distance between power supplies	Short	Moderate	Long
Supports	Isolated supports recommended	Isolated supports required	Isolated supports recommended
Magnetic isolation required	Yes	Yes	No
Oversized insulation required	No	No	Yes, or notching
Power density available	High	High	Moderate
Voltage on pipe	Low	Low	None
Metallic pipe required	Yes	Yes	No
Ferromagnetic tube required	No	No	Yes, for heat tube

7.4.4.1 Classified areas

Where equipment is installed in a classified area, the class, division or zone, group, and minimum ignition temperature should be specified. As an alternative to ignition temperature, the appropriate identification number listed in Table 500-5(d) or Table 505-10(b) in National Electric Code[®] (NEC[®]) NFPA 70-1999, or an equivalent standard, may be specified. The maximum runaway sheath/pipe temperature must be calculated in accordance with Clause 6, IEEE Std 515-1997 [B16].

7.4.5 Electrical supply system

Characteristics of the electrical supply system should be determined, including locations of power control centers, voltages, phase, frequency, continuous capacity, and short-circuit capacity available.

7.4.6 Cooling water

Source and quality of cooling water should be known if high-watt density induction coils are to be considered.

7.4.7 Adequacy and safety

Design for all three of these types of heating systems is usually handled as a part of a complete system furnished by the vendor of the system who assumes responsibility for the adequacy and safety of the system.

7.4.8 User review

All three systems use electric power to heat metallic pipes or vessels. The user of any of these systems should review the entire system, both mechanically and electrically, to assure proper equipment use and personnel safety.

Although it is impossible to recommend guidelines that cover all possible conditions, some common considerations are as follows:

- a) Maximum surface temperature of the thermal insulation or the weather barrier; see 5.4.1.
- b) Grounding and use of ground fault circuit interrupters for personnel and/or equipment protection. An electrical failure that results in arcing may cause physical damage to the pipeline or the vessel.
- c) Pipelines or vessels being electrically heated will expand and contract and may cause damage to connections, supports, thermal or electrical insulation, or devices near or attached to the pipe or the vessel. The resulting physical damage could rupture the pipeline or the vessel and expose electrically or thermally hot elements. Such exposure could result in arcing, burning, or a potential shock hazard to personnel.

7.5 Power systems

7.5.1 Higher frequency power sources

All three systems use power at a normal power frequency. If control by variable frequency, or higher frequency for thin-walled vessels, is necessary for induction heating, then rotating or static converters must be supplied. All system loads are single-phase, but where loads can be divided, they can be connected three-phase, or a Scott T-connected transformer can be used to produce two-phase from three-phase. A tripler circuit can be employed to supply single-phase, 180 Hz loads from three-phase, 60 Hz lines.

7.5.2 Special transformers

Voltage requirements depend upon the characteristics of each individual heating system. In most systems, transformers with special output voltages are required.

7.5.3 Power quality

Except when analog power controls are used, the power distribution system serving these heating systems requires no special considerations if they have been designed and installed in accordance with NEC and IEEE Std 141-1986, or an equivalent standard. If single-phase loads are not converted to three-phase loads,