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Electrical resistance trace heating systems for industrial and commercial applications

Part 2: Application guide for system design, installation and maintenance

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The UK participation in its preparation was entrusted to Technical Committee PEL/27, Electroheating.

A list of organizations represented on this committee can be obtained on request to its secretary.

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© The British Standards Institution 2013.
Published by BSI Standards Limited 2013

ISBN 978 0 580 77528 4
ICS 25.180.10

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 December 2013.

Amendments/corrigenda issued since publication

Date	Text affected
------	---------------

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 62395-2

December 2013

ICS 25.180.10

Supersedes CLC/TS 62395-2:2010

English version

**Electrical resistance trace heating systems for industrial
and commercial applications -
Part 2: Application guide for system design, installation and maintenance
(IEC 62395-2:2013)**

Systèmes de traçage par résistance
électrique pour applications industrielles
et commerciales -
Partie 2: Guide d'application pour la
conception, l'installation et la maintenance
du système
(CEI 62395-2:2013)

Elektrische Widerstands-Begleitheizungen
für industrielle und gewerbliche Zwecke -
Teil 2: Anwendungsleitfaden für
Systementwurf, Installation und Wartung
(IEC 62395-2:2013)

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Ref. No. EN 62395-2:2013 E

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Foreword

The text of document 27/927/FDIS, future edition 1 of IEC 62395-2, prepared by IEC/TC 27 "Industrial electroheating and electromagnetic processing" was submitted to the IEC-CENELEC parallel vote and approved by CENELEC as EN 62395-2:2013.

The following dates are fixed:

- latest date by which the document has to be (dop) 2014-07-14
implemented at national level by
publication of an identical national
standard or by endorsement
- latest date by which the national (dow) 2016-10-14
standards conflicting with the
document have to be withdrawn

This document supersedes CLC/TS 62395-2:2010.

EN 62395-2:2013 includes the following significant technical changes with respect to CLC/TS 62395-2:2010:

- this document has been changed from a Technical Specification to a European Standard;
- design considerations for trace heating on sprinkler systems have been expanded and a figure has been added to illustrate how to avoid undue shadowing of spray patterns from insulated sprigs close to sprinkler heads;
- specific details of design considerations for trace heating for emergency eyewash units and safety showers have been added.

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Endorsement notice

The text of the International Standard IEC 62395-2:2013 was approved by CENELEC as a European Standard without any modification.

In the official version, for Bibliography, the following notes have to be added for the standards indicated:

IEC 60079-30-1:2007	NOTE	Harmonized as EN 60079-30-1:2007 (not modified).
IEC 60079-30-2:2007	NOTE	Harmonized as EN 60079-30-2:2007 (not modified).
IEC 60335-2-83:2001	NOTE	Harmonized as EN 60335-2-83:2002 (not modified).
IEC 60335-2-83:2001/A1:2008	NOTE	Harmonized as EN 60335-2-83:2002/A1:2008 (not modified).
IEC 60335-2-96:2002	NOTE	Harmonized as EN 60335-2-96:2002 (not modified).
IEC 60335-2-96:2002/A1:2003	NOTE	Harmonized as EN 60335-2-96:2002/A1:2004 (not modified).
IEC 60335-2-96:2002/A2:2008	NOTE	Harmonized as EN 60335-2-96:2002/A2:2009 (not modified).

Annex ZA (normative)

Normative references to international publications with their corresponding European publications

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

NOTE When an international publication has been modified by common modifications, indicated by (mod), the relevant EN/HD applies.

<u>Publication</u>	<u>Year</u>	<u>Title</u>	<u>EN/HD</u>	<u>Year</u>
IEC 60519-1	-	Safety in electroheating installations - Part 1: General requirements	EN 60519-1	-
IEC 62395-1	2013	Electrical resistance trace heating systems for industrial and commercial applications - Part 1: General and testing requirements	EN 62395-1	2013

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INTRODUCTION

IEC 62395-1 provides the essential requirements and testing appropriate to electrical resistance trace heating equipment used in industrial and commercial applications. While some of this work already exists in national or international standards, this standard has collated much of this existing work and added considerably to it.

IEC 62395-2 provides detailed recommendations for the system design, installation, maintenance and repair of electrical resistance trace heating systems in industrial and commercial applications which can include piping, vessels, roofs and concrete slab heating applications.

It is the objective of IEC 62395 that, when in normal use, electrical trace heating systems operate safely under their defined conditions of use, by

- a) employing heaters of the appropriate construction so as to meet the test criteria and requirements detailed in IEC 62395-1. The construction includes a metallic sheath, braid, screen or equivalent electrically conductive covering;
- b) operating at safe temperatures when designed, installed, and maintained in accordance with IEC 62395-2;
- c) having at least the minimum levels of overcurrent and earth-fault protection required in IEC 62395-1 and IEC 62395-2.

ELECTRICAL RESISTANCE TRACE HEATING SYSTEMS FOR INDUSTRIAL AND COMMERCIAL APPLICATIONS —

Part 2: Application guide for system design, installation and maintenance

1 Scope

This part of IEC 62395 provides detailed recommendations for the system design, installation, maintenance and repair of electrical resistance trace heating systems in industrial and commercial applications. This standard does not include or provide for any applications in potentially explosive atmospheres.

This standard pertains to trace heating systems that may comprise either factory fabricated or field-assembled (work-site) units, and which may be series or parallel trace heaters, or surface heaters (heater pads or heater panels) that have been assembled and/or terminated in accordance with the manufacturer's instructions.

The products covered by this standard are intended to be installed by persons who are suitably trained in the techniques required and that only trained personnel carry out especially critical work, such as the installation of connections and terminations. Installations are intended to be carried out under the supervision of a qualified person who has undergone supplementary training in electric trace heating systems.

This standard does not cover induction, impedance or skin effect heating.

Trace heating systems can be grouped into different types of installations. These are characterized by different requirements for testing and are usually certified for a specific type of installation or application. Typical applications for the different types of installation are as follows:

- a) Installations of trace heating on pipes, vessels and associated equipment. Applications include:
 - freeze protection and temperature maintenance;
 - hot water lines;
 - oil and chemical lines;
 - sprinkler systems.
- b) Outdoor exposed area installations of trace heating. Applications include:
 - roof de-icing;
 - gutter and downspout de-icing;
 - catch basins and drains;
 - rail heating.
- c) Installation with embedded trace heating. Applications include:
 - snow melting;
 - floor warming;
 - frost heave prevention;
 - underground thermal energy storage systems;
 - door frames.

d) Installations of trace heating internal to conduit or piping. Applications include:

- snow melting – in conduit;
- floor warming – in conduit;
- frost heave prevention – in conduit;
- underground thermal energy storage systems – in conduit;
- internal trace heating of potable water lines;
- enclosed drains and culverts.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60519-1, *Safety in electroheating installations – Part 1: General requirements*

IEC 62395-1:2013, *Electrical resistance trace heating systems for industrial and commercial applications – Part 1: General and testing requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in IEC 60519-1 and IEC 62395-1:2013 apply.

NOTE General definitions are given in the International Electrotechnical Vocabulary, IEC 60050. Terms relating to industrial electroheat are defined in IEC 60050-841.

4 Surface heating of vessels and piping systems

4.1 Application description

4.1.1 General

Piping and vessels often utilise surface-mounted trace heating systems to maintain water above freezing-point and to maintain process fluids and gases at given temperature levels. The trace heaters compensate for heat losses to the environment that are reduced but not eliminated by thermal insulation.

4.1.2 Environmental conditions

Attention should be directed to the surrounding environmental conditions, especially for systems that are exposed to sunlight (ultraviolet exposure), coastal atmospheres (corrosive salt spray and high humidity), and chemical atmospheres such as oil refineries and chemical plants.

Equipment subject to ultraviolet exposure may degrade due to surface oxidation, which can possibly lead to surface embrittlement and cracking. Corrosive atmospheres can affect the same exposed surfaces and can accelerate degradation of surfaces that are also susceptible to ultraviolet exposure. Chemical exposure can affect all equipment, whether covered by thermal insulation or not.

The trace heating equipment for piping and vessels is often protected from corrosion and ultraviolet exposure to some degree by the thermal insulation. However, these systems can have components that are exposed to the environment such as electrical connection

components and weather barrier around the thermal insulation. The selection of trace heating equipment shall include a review of the suitability of equipment to the expected environmental conditions.

4.1.3 Trace heating systems considerations

Trace heating systems can range from simple pipe freeze protection in commercial buildings to process temperature maintenance and heat-up applications in large complex piping/vessel systems in industrial facilities. The details required for design can vary based on the complexity of the application. Control systems and requirements for monitoring can also vary depending on the control and design requirements.

Trace heating equipment should be chosen that is suitable for the application. For example, plastic piping has a much lower maximum exposure temperature than metallic piping. The trace heating and control system shall keep the piping temperature within the allowed range.

Higher temperature processes shall utilize trace heating and thermal insulation equipment that are suitable for the maximum exposure temperatures.

4.2 Design information – General

4.2.1 General

The requirements for system design include the development of basic heat loss (load) requirements, installation instructions for electrical, control and monitoring requirements, and trace heating system layouts for large, detailed, complex installations such as industrial facilities. While each design component requires individual treatment, the final system shall be evaluated as an integration of these component parts.

Trace heating system design shall conform to all IEC requirements for the use of electrical equipment and to the requirements of this standard. Consideration should be given to the maintenance of the trace heating systems to maintain energy efficiency and to routine testing of the installed systems for safe and proper operation.

Persons involved in the design and planning of electric trace heating systems should be suitably trained in all techniques required.

4.2.2 Electrical system design

The evaluation of electrical resistance heating systems includes an initial assessment of energy requirements and the associated electrical distribution equipment. The selection of the type of trace heating equipment and the control equipment affects the requirements of the electrical system design. Additional information is given in 4.4.

4.2.3 Control and monitoring

4.2.3.1 General

Controls for trace heating systems are often specified to reduce total energy usage and/or to maintain particular processes within a narrow band. Monitoring systems are used to verify correct system operation and in many cases to provide an indication of electrical problems or temperatures that are out of range. Subclause 4.2.3.2 describes the basic types of controls and monitoring and 4.2.3.3 defines critical applications relative to the control systems. Specific design of control systems is given in 4.5.

4.2.3.2 Recommendations for control

The recommendations for control and monitoring are defined by the type of application.

a) Type I

A Type I control is for applications where the temperature is maintained above a minimum point. Large blocks of power may be controlled by means of a single control device, such as ambient sensing, and an electrical distribution panel board. Heat input may be provided unnecessarily at times and wide temperature excursions should be tolerable. Energy efficiency may be improved through the use of dead-leg control techniques (see 4.5.10).

b) Type II

A Type II control is for applications where the temperature should be maintained within a moderate band. Control by pipe-sensing mechanical thermostats is typical.

c) Type III

A Type III control is for applications where the temperature should be controlled within a narrow band. Electronic pipe-sensing controllers using thermocouple or resistance-temperature detector (RTD) units facilitate field (work site) calibration and provide maximum flexibility in the selection of temperature alarm and monitoring functions. Heat input capability may be provided to preheat an empty pipe or raise the fluid temperature, or both, within a specified range and time interval. Type III systems require strict adherence to flow patterns and thermal insulation systems.

4.2.3.3 Control and monitoring for critical applications

If failure of any part of the trace heating system can result in a safety or operability problem, then the trace heating system may be considered to be critical to the application. The temperature control and circuit monitoring requirements of an application may be defined according to the temperature control types described in 4.2.3.2, together with the control level as described in Table 1.

Table 1 – Application types

Is trace heating a critical component for the application?	Desired accuracy of temperature control		
	Above a minimum point Type I	Within a moderate band Type II	Within a narrow band Type III
Yes = Critical (C–)	C – I	C – II	C – III
No = Non-critical (NC–)	NC – I	NC – II	NC – III

When trace heating is critical to the application, circuit monitoring for correct operation, malfunction alarms, and back-up (redundant) trace heaters should be considered. Redundant trace heaters may allow maintenance or repairs to be performed without a process shutdown and may be used to enhance reliability. Redundant controllers can be specified to be automatically activated in the event of a fault being indicated by the monitoring/alarm system.

4.2.4 Trace heating system design

Trace heaters should be selected to provide sufficient power for

- compensation of heat loss when maintaining a specified temperature of an application, see the calculation method in 4.3.4; and/or
- raising the temperature of a workpiece and its contents when specified, within a specified time period, see the calculation method in 4.3.6.

The evaluation should provide an electrical system with sufficient capacity to deliver the required power at the specified minimum ambient temperature. The system heat requirements should be multiplied by a safety factor as determined on the basis of 4.3.5. Additional specific design recommendations are described in 4.6.

4.2.5 Design information documentation

Design information may be compiled and provided in the form of specifications, layouts, and other system documentation and drawings. Any or all of the following may be applicable.

- thermal design parameters;
- system flow diagram;
- equipment layout drawings (plans, sections, etc.);
- pipe drawings (plans, isometrics, line lists, etc.);
- piping specifications;
- thermal insulation specifications;
- equipment detail drawings (pumps, valves, strainers, etc.);
- electrical drawings (one lines, elementaries, etc.);
- bill of materials;
- electrical equipment specifications;
- equipment installation and instruction manuals;
- equipment details;
- thermal insulation schedules;
- process procedures that would cause elevated pipe temperatures, that is, steam out or exothermic reactions.

4.3 Thermal system design

4.3.1 General

Trace heater selection includes the determination of the maximum possible system temperature under worst-case conditions. The evaluation shall ensure that the maximum system temperature does not exceed the maximum withstand temperature rating of the workpiece or the thermal insulation. The trace heating supplier should also provide recommendations for these applications, including product performance and installation guidelines.

The trace heater sheath temperature and/or the maximum workpiece temperature may be reduced by, for example, the use of multiple tracers to reduce the power produced per unit length or by the selection of the temperature control system.

Subclause 4.3 reviews design parameters, thermal insulation considerations, system heat loss, safety factors, heat-up considerations, selection of trace heater, design calculations, sheath temperature calculations, design documentation, start-up at low ambient temperatures, long trace heater circuits, and chimney effect.

4.3.2 Design conditions

The following general design conditions and application inputs are typically needed prior to commencing with the system design. Additional information that may be required for particular applications is detailed in 4.6.

a) System parameters:

- 1) pipe and vessel maintain temperature;
- 2) minimum ambient temperature;
- 3) insulation thickness and type;
- 4) pipe diameters, lengths, and routing (vertical, horizontal, oblique) or vessel dimensions;
- 5) pipe type:
 - i) non-metallic;
 - ii) metallic;
- 6) components such as pumps, strainers, flanges, valves, and supports;

- 7) maximum process temperature (due to process, steam cleaning, etc.);
 - 8) flow characteristics:
 - i) pressurized;
 - ii) gravity;
 - 9) design wind velocity.
- b) Electrical considerations:
- 1) voltage supply;
 - 2) circuit locations;
 - 3) power distribution system.

4.3.3 Thermal insulation

4.3.3.1 General

The selection, installation and maintenance of thermal insulation should be considered a key component in the performance of an electrical trace heating system. The thermal insulation system is normally designed to prevent the majority of heat loss with the trace heating system compensating for the remainder. Therefore, problems with thermal insulation have a direct impact on the overall system performance.

The principal areas for consideration are as follows:

- selection of an insulating material;
- selection of a weather barrier (cladding);
- selection of the economic insulation thickness;
- the double insulation method.

4.3.3.2 Selection of insulating material

The following are important aspects to be considered when selecting an insulation material. These factors should be considered and the selection optimized according to the following design criteria:

- temperature rating;
- thermal conductivity of the insulation;
- mechanical properties;
- chemical compatibility and corrosion resistance;
- moisture resistance;
- health risks during installation;
- fire resistance;
- toxicological properties when exposed to fire;
- costs.

Insulating materials commonly available include:

- expanded silica;
- mineral fibre;
- cellular glass;
- urethane;
- fibreglass;
- calcium silicate;
- polyisocyanurate;

- perlite silicate.

For soft insulants (mineral fibre, fibreglass, etc.), actual pipe size insulation may be used in many cases by banding the insulation tightly. Care should be taken to prevent the trace heater from being buried within the insulation, which may cause damage to the trace heater or may restrict proper heat transfer. As an alternative, the next larger pipe size insulation that can easily enclose pipe and electric trace heater is also acceptable. Rigid insulation (calcium silicate, expanded silica, cellular glass, etc.), may be pipe-size insulation if customized to fit the longitudinal joint. In all cases, the insulation type, size and thickness should be clearly specified.

Insulation for valves, flanges, pumps, instruments, and other irregularly shaped equipment are typically custom fit for the particular configuration. This may be fabricated from block, insulation segments or flexible removable covers.

Insulating cements or fibrous materials should be used to fill cracks and joints. Where used for total insulation of an irregular surface, a proportionally thicker layer of insulating cement may be applied to achieve the desired insulating capability. When using insulating cement, install a barrier over the trace heater to prevent the insulating cement from isolating the trace heater cable from the workpiece (creating excessive heater temperatures).

Embedding the trace heater in insulation cements should generally be avoided.

4.3.3.3 Selection of weather barrier (cladding)

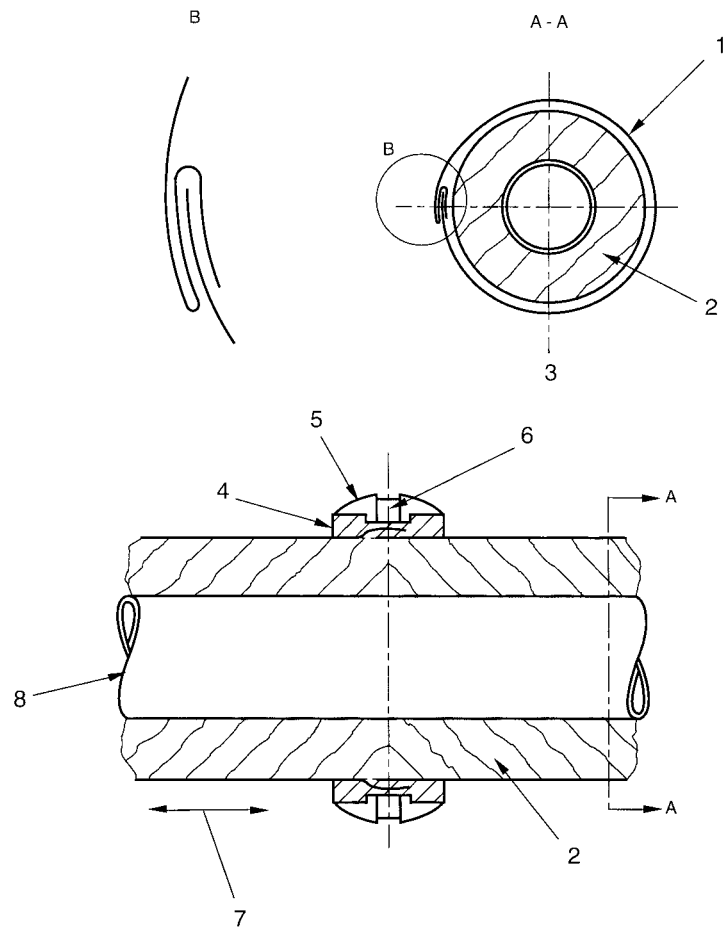
Proper operation of an electrically trace heated system depends upon the insulation being dry. Electric tracing normally has insufficient heat output to dry out wet thermal insulation. Some insulation materials, even though removed from the piping and force dried, never regain their full insulating capability once they have been wet.

Straight piping should be weather-protected with metal or polymeric jacketing or a mastic system. When metal jacketing is used, it should be smooth with formed, modified “S” longitudinal joints. The circumferential end joints should be sealed with closure bands and supplied with sealant on the outer edge or where they overlap (see Figure 1).

Jacketing that is 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 during a rainstorm.

The type of weather barrier should be determined based on the following:

- effectiveness in excluding moisture;
- corrosive nature of chemicals in the area;
- fire protection requirements;
- durability to mechanical abuse;
- cost.



IEC 748/08

Key

- | | |
|-------------------------------|-------------------|
| 1 Metal jacket | 5 Closure band |
| 2 Insulation | 6 Insulated strap |
| 3 Metal jacket insulated pipe | 7 Movement |
| 4 Mastic sealer | 8 Pipe |

Figure 1 – Thermal insulation – Weather-barrier installation

4.3.3.4 Sealing of weather barrier penetrations

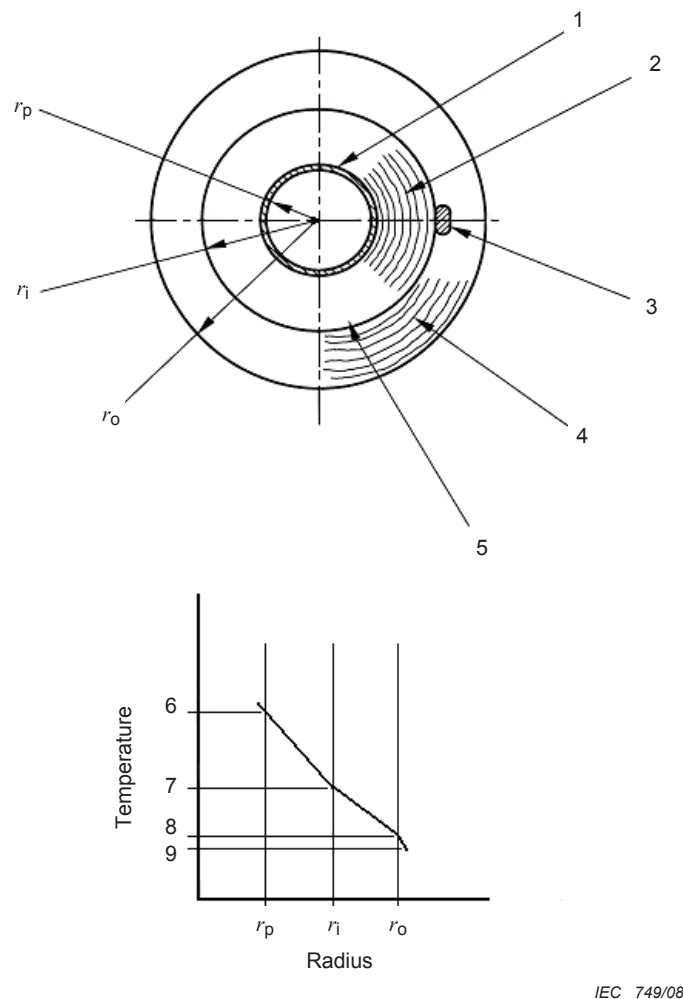
Quality caulking of weather barrier penetrations is required to prevent water ingress and contamination of thermal insulation systems. Structural supports and trace heater connection kits are examples of such penetrations. Low quality caulking materials dry out and crack, allowing gaps for water ingress.

4.3.3.5 Selection of economical thickness

At a minimum, an economic evaluation of the insulation considers the initial costs of the materials and installation against the energy saved over the life of the system. It should be noted that the actual insulation thicknesses do not always correspond exactly to the nominal insulation thickness. When choosing the insulation size, considerations should be made as to whether or not the actual pipe-size insulation is suitable for accommodating both pipe and trace heater.

4.3.3.6 Double insulation method

The double insulation technique may be employed when the pipe temperature exceeds the maximum allowable temperature of the trace heater. A typical application is prevention of the freezing of condensate in high-temperature steam lines when these lines are not in use. The trace heater is located between two layers of insulation surrounding the pipe. The essence of the double-insulation technique is to determine the correct combination of inner and outer insulation type and thickness that results in an acceptable interface temperature for the trace heater. The inner layer of thermal insulation circumferential end joints should be installed with gaskets to prevent opening of gaps as piping heats up. Gaps may cause high temperatures to reach and damage the trace heater. The installation is illustrated and a typical temperature profile is indicated graphically in Figure 2. It should be noted that the maximum ambient temperature conditions should be considered in this determination.



Key

- | | |
|--------------------------|--|
| 1 Pipe | 6 Pipe temperature |
| 2 Inner insulation layer | 7 Interface temperature |
| 3 Heat tracer | 8 Outer insulation surface temperature |
| 4 Outer insulation layer | 9 Ambient temperature |
| 5 Metal foil (aluminium) | |

Figure 2 – Typical temperature profile

4.3.4 Heat loss determination

The heat loss of a workpiece can be calculated from the following formula incorporating both conduction and convection parameters:

$$q = \frac{(T_p - T_a)}{\frac{1}{\pi D_1 h_i} + \frac{\ln\left(\frac{D_2}{D_1}\right)}{2\pi k_1} + \frac{\ln\left(\frac{D_3}{D_2}\right)}{2\pi k_2} + \frac{1}{\pi D_3 h_{co}} + \frac{1}{\pi D_3 h_o}} \quad (1)$$

where

- q is the heat loss per unit length of pipe in watts per metre (W/m);
- T_p is the desired maintenance temperature in degrees Celsius (°C);
- T_a is the minimum design ambient temperature in degrees Celsius (°C);
- D_1 is the inside diameter of the inner insulation layer in metres (m);
- D_2 is the outside diameter of the inner insulation layer in metres (m) (inside diameter of the outer insulation layer when present);
- D_3 is the outside diameter of the outer insulation layer when present in metres (m);
- k_1 is the thermal conductivity of the inner layer of insulation evaluated at its mean temperature (W/mK);
- k_2 is the thermal conductivity of the outer layer of insulation, when present, evaluated at its mean temperature (W/mK);
- h_i is the inside air contact convection coefficient from the pipe to the inner insulation surface when present (W/m²K);
- h_{co} is the inside air contact convection coefficient from the outer insulation surface to the weather barrier when present (W/m²K);
- h_o is the outside air film convection coefficient from the weather barrier to ambient (W/m²K) (typical values for this term range from 5 W/m²K to 50 W/m²K for low-temperature applications below 50 °C);
- $\ln$ is the natural log to base e.

The degree of accuracy of the calculation depends on the degree of definition of the system parameters.

The basic formula given in (1) can be reduced to the following form for pipes and tubes when only the conduction parameters are taken into account and when only one thermal insulation layer is present:

$$q = \frac{2\pi k (T_p - T_a)}{\ln\left(\frac{D_2}{D_1}\right)} \quad (2)$$

Vessel heat losses often require a more complex analysis to determine total heat loss. The trace heating supplier should be consulted.

For ease of product selection, trace heating suppliers often furnish simple charts and graphs and/or computer programs to determine heat losses for variously maintained temperatures and insulations, which usually include a safety factor.

The preceding relationships assume that the thermal insulation system densities, volumes, conductivities and heat losses are constant over the temperature range of interest. Although

the model is representative of a straight pipeline, it does not have provisions for equipment such as pumps and valves. Non-insulated or partially insulated pipe supports or equipment require additional heat input to compensate for the higher heat loss.

4.3.5 Design safety factor

Since heat-loss calculations based on theoretical values do not account for imperfections associated with actual work site installations, a safety factor should be applied to the calculated values. The safety factor should be based upon the user's requirement: this typically increases the heat loss by 10 % to 25 %. A more detailed evaluation should include the following:

- a) thermal insulation degradation;
- b) supply voltage variations;
- c) branch wiring voltage drop;
- d) trace heater voltage drop;
- e) increased radiation and convection on higher temperature applications;
- f) quality of installation of thermal insulation.

4.3.6 Heat-up considerations

In certain plant operations, it may be necessary to specify that the trace heating system is capable of raising the temperature of a static product within a certain time period. The heat-up time (in seconds) of a trace heated system on piping may be calculated by use of the following formula.

$$t = H \ln \left\{ \frac{q_c - U(T_i - T_a)}{q_c - U(T_f - T_a)} \right\} + \frac{P_1 V_{c1} h_f}{q_c - U(T_{sc} - T_a)} \quad (3)$$

where

U is the heat loss per unit length of pipe per degree of temperature difference:

$$U = \frac{1}{\frac{1}{\pi D_1 h_i} + \frac{\ln \left(\frac{D_2}{D_1} \right)}{2\pi K_1} + \frac{\ln \left(\frac{D_3}{D_2} \right)}{2\pi K_2} + \frac{1}{\pi D_3 h_{co}} + \frac{1}{\pi D_3 h_o}} \quad (4)$$

H is the thermal time constant, which is the total energy stored in the mass of pipe, fluid, and insulation per degree of temperature divided by the heat loss per unit length per degree temperature differential, as follows:

$$H = \frac{P_1 C_{p1} V_{c1} + P_2 C_{p2} V_{c2} + 0.5 P_3 C_{p3} V_{c3}}{U} \quad (5)$$

where

- P_1 is the density of the product in the pipe (kg/m³);
- C_{p1} is the specific heat of the product (J/kgK);
- V_{c1} is the internal volume of the pipe (m³/m);
- P_2 is the density of the pipe (kg/m³);
- C_{p2} is the specific heat of the pipe (J/kgK);
- V_{c2} is the pipe wall volume (m³/m);
- P_3 is the density of insulation (kg/m³);
- C_{p3} is the specific heat of the insulation (J/kgK);

V_{c3}	is the insulation wall volume (m^3/m);
T_i	is the initial temperature of the pipe ($^{\circ}C$);
T_f	is the final temperature of the fluid and the pipe ($^{\circ}C$);
T_a	is the ambient temperature ($^{\circ}C$);
T_p	is the desired maintenance temperature ($^{\circ}C$);
t	is the desired heat-up time in seconds (s);
U	is the heat loss per unit length of pipe per degree of temperature (W/mK);
H	is the thermal time constant in seconds (s);
T_{sc}	is the temperature at which the phase change occurs ($^{\circ}C$);
h_f	is the latent heat of fusion for the product (J/kg);
q_c	is the output of the trace heater(s) (W/m).

It may be necessary to evaluate the heat requirement separately for a phase change in heat-up applications.

4.3.7 Selection of trace heater

4.3.7.1 General

Basic selection criteria for trace heaters shall include the following.

- The maximum withstand temperature of trace heaters shall be greater than the maximum possible workpiece temperature (which may be greater than the normal operating temperature).
- Trace heaters shall be suitable for operation in the environmental conditions specified, for example, a corrosive atmosphere or a low ambient temperature.
- Trace heaters shall meet the requirements of IEC 62395-1:2013 for use in the particular application.

Site-fabricated trace heaters are permissible provided that:

- installation personnel are competent in the special techniques required;
- trace heaters pass the field (site work) tests specified;
- trace heaters are marked in accordance with the requirements of IEC 62395-1:2013.

It is necessary to determine the maximum allowable power density for each circuit design, such that temperature limits are not exceeded. This is typically determined by theoretical formulae and then adjusted as necessary based on the trace heating supplier's empirical data. The limiting value of maximum allowable power density for each trace heater is either the value chosen from the supplier's data or that specified for the system, whichever is the lower. The power density may be reduced if needed by the use of multiple tracing.

The actual installed load should be not less than the design loading and the actual power density not greater than that obtained above. Multiple tracing or spiralling of a single trace heater may be required. The type of trace heater and the values of installed load and power density should be recorded in the system documentation.

4.3.7.2 Specific types of trace heaters

Trace heaters are generally defined by their electrical characteristics.

Series trace heaters typically use the electrical conductor as the heating element, in such a way that the voltage supply and circuit length become critical parameters in the design of each circuit. Series trace heaters with polymeric insulation are particularly suited for installations with long circuit lengths. Series trace heaters with mineral insulation (MI) and

metallic sheaths are particularly suited for very high process temperature and high watt-density applications.

Parallel trace heaters typically consist of two parallel conductors with a separate polymeric or metallic heating element that draws voltage from the conductors. These are characteristically used for freeze protection and for temperature maintenance of complex piping installations. The constant wattage type typically has a spirally wound metallic heating element. The PTC type (positive temperature coefficient, see 4.3.7.4) typically consists of a polymeric heating element extruded between the conductors. The power-limiting type typically falls between the previous types, with higher output at higher operating temperatures than the PTC type, and with lower maximum sheath temperatures than the constant wattage type.

4.3.7.3 Selecting the trace heater

When selecting trace heaters the objective should be to minimize the overall installed cost while ensuring the overall reliability and maintainability of the system. It is important to first define the characteristics of different applications.

- Complex piping systems consist of relatively short runs of pipe with frequent tees as well as inline valves and pumps that also require trace heating. While variations occur depending on the control requirements, the average circuit length is typically less than 30 m.
- Interconnecting piping systems are those connecting different areas of an industrial facility and are generally much longer than complex piping. The lengths may be up to 1 500 m and have little inline equipment or branch flow paths.
- Product transfer lines are found in applications like barge-unloading lines and in tank farms.

4.3.7.4 Trace heater performance and equilibrium conditions

Figure 3 shows examples of power output curves for a constant wattage trace heater and for two PTC (positive temperature coefficient) trace heaters with different slope characteristics. The figure also indicates the heat loss through the thermal insulation for a given ambient temperature (in this example -20°C), and how the heat loss increases as the workpiece temperature increases. In this case the heat loss at the desired maintenance temperature of 10°C is 15 W/m . The figure indicates that the trace heater shall supply a minimum of 15 W/m regardless of the type of trace heater selected.

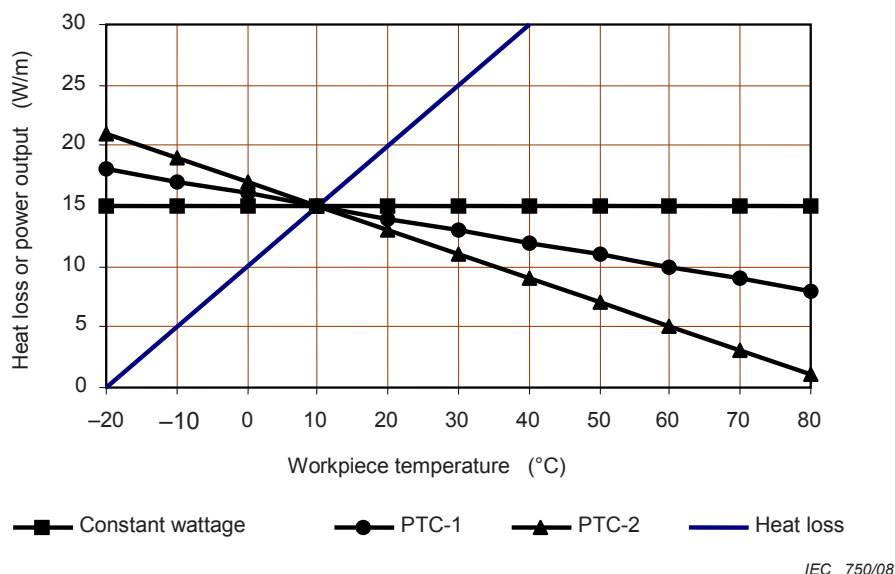


Figure 3 – Equilibrium conditions for workpiece maintenance

Figure 4 shows the same example but from the perspective of evaluating the upper limits. The heat loss line is now plotted for the highest ambient temperature (in this case 40 °C). Also, the trace heater output levels have been increased to illustrate maximum output tolerance. The intersection points (where heat loss is equal to heat input) indicate the highest possible workpiece temperature and the power outputs at these conditions. For example, the potential maximum workpiece temperature for the constant wattage trace heater is 73 °C, and the heat loss and potential maximum trace heater output level are at equilibrium at 17 W/m. Both PTC-1 and PTC-2 indicate somewhat lower maximum workpiece temperatures due to the decreasing slope of the output curves. PTC-2 indicates a potential maximum workpiece temperature of 56 °C, and the heat loss and potential maximum trace heater output level are at equilibrium at 8 W/m. This approach may be used when evaluating the upper limit operating conditions for the stabilized design approach.

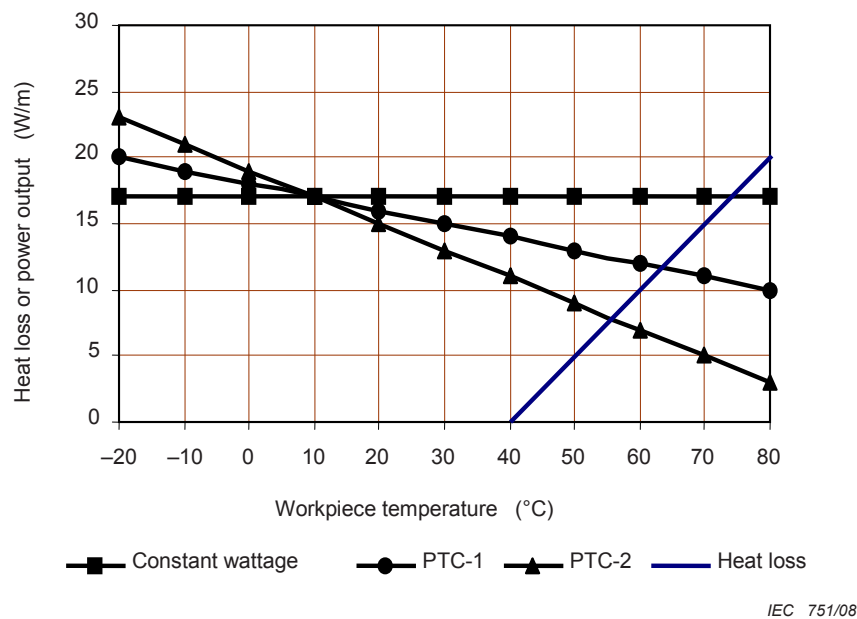


Figure 4 – Equilibrium conditions for upper limit evaluation

The power output levels of different trace heaters are typically provided by the trace heater supplier in the product literature and/or in a design program. In most cases, the output curves for the PTC trace heater types are defined based on empirical data from test fixtures similar to the test in 5.2.10 of IEC 62395-1:2013.

4.3.8 Design calculations

4.3.8.1 General

The following characteristics of a trace heating system design should exist for the trace heating system to meet the specified requirements.

- The output of trace heaters shall be greater than the system heat loss including a suitable safety factor. This can be achieved by installing a single trace heater with suitable output, by using multiple passes, or by spiralling if needed to keep the output level as low as possible.
- Potential variations in voltage supply and other system parameters should be determined and compensated for by a safety factor.
- The upper limit characteristics of the system (for example, amperage, heater and workpiece temperatures) shall be evaluated for applications where process temperature accuracy is critical, that have a wide range of ambient temperatures, that have no temperature controller, or that utilize ambient sensing control.

4.3.8.2 Stabilized design

Stabilized design is based on the principle of determining the maximum workpiece and trace heater surface temperatures under a worst-case set of conditions. This is a calculation of the equilibrium conditions that occur when the heat input equals the system heat loss. The worst-case set of conditions includes:

- a) maximum ambient temperature, typically assumed to be 40 °C unless otherwise specified;
- b) no wind (still air);
- c) use of a conservative or minimum value for the thermal conductivity of the thermal insulation;
- d) no temperature control as per the design or to simulate a failed temperature controller;
- e) the trace heater is operated at its stated operating voltage plus 10 %;
- f) the trace heater is assumed to be operating at the upper limit of the manufacturing tolerance, or at the minimum specific resistance for series trace heaters.

This set of circumstances is illustrated graphically in Figure 4. Testing for stabilized design is defined in 5.2.13 of IEC 62395-1:2013. Typically, the maximum surface temperature of the trace heater is calculated from formulae derived from the evaluation of empirical data, or by the theoretical approach described below. Many trace heating suppliers have design programs that calculate the maximum surface temperature on the basis of these worst-case parameters.

4.3.9 Theoretical sheath temperature calculations – Metallic pipe applications

The maximum possible pipe temperature is calculated at maximum ambient temperature with the trace heater continuously energized. The formula for calculating the maximum potential pipe temperature is a rearrangement of the terms of the heat loss formula.

$$T_{pc} = \frac{Q_{sf}}{\pi} \left[\frac{1}{D_1 h_i} + \frac{\ln\left(\frac{D_2}{D_1}\right)}{2k} + \frac{1}{D_2 h_{co}} + \frac{1}{D_2 h_o} \right] + T_a \quad (6)$$

where

T_{pc} is the maximum calculated pipe temperature (°C);

NOTE The maximum process pipe temperature can sometimes exceed the calculated value.

Q_{sf} is the upper tolerance trace heater output (W/m);

k is the thermal conductivity of the insulation at its mean temperature (W/mK);

Other terms are defined in earlier formulae. Iterative techniques may need to be applied to the calculation of Formula (6) in order to arrive at T_{pc} , since the thermal conductivity of the insulation and the trace heater output may be a function of pipe temperature.

The sheath temperature of a trace heater may be calculated as follows:

$$T_{sh} = \frac{Q_{sf}}{UC} + T_{pc} \quad (7)$$

where

T_{sh} is the trace heater sheath temperature (°C);

C is the trace heater circumference (m);

U is the overall heat transfer coefficient (W/m²K).

The overall heat transfer coefficient is different for each trace heater type, installation method and system configuration. It is a combination of conductive, convective and radiation heat transfer modes. The value of U can vary from 12 W/m²K for a cylindrical trace heater in air (primarily convective) to 170 W/m²K or more for a trace heater applied using heat transfer aids (primarily conductive). Upon request, the trace heating supplier should provide the U -factor for given applications, or furnish calculated or experimentally determined sheath temperatures.

The actual power output of the trace heater should not exceed the stated upper tolerance output, and the operating sheath temperature should not exceed the calculated maximum sheath temperature.

4.3.10 Theoretical sheath temperature calculations – Non-metallic pipe applications

For non-metallic pipe applications, the pipe wall thermal resistance should be considered, as the non-metallic pipe is a poor heat transfer medium. These materials may have a thermal conductivity (k -factor) 1/200 of that of steel, and a substantial temperature difference may develop across the pipe or tank wall depending on the trace heater power density. This higher than normal temperature (when compared to tracing metallic pipes and vessels) may have two adverse effects:

- a) the non-metallic pipe maximum allowable temperature may be exceeded;
- b) the trace heater maximum allowable sheath temperature may be exceeded.
- c) The sheath temperature of the trace heater under normal operating conditions is in principle obtained from Formula (7). However, in obtaining U , the effect of the thermal resistance of the pipe wall should be included. The overall heat transfer coefficient for plastic pipe is

$$\frac{1}{U_p} = \frac{1}{U_m} + \frac{L}{k_p} \quad (8)$$

where

- U_p is the overall heat transfer coefficient for a non-metallic pipe (W/m²K);
 U_m is the overall heat transfer coefficient for a metallic pipe (W/m²K);
 L is the pipe wall thickness in metres (m);
 k_p is the thermal conductivity of the pipe wall material (W/mK).

Because of the additional thermal resistance of the non-metallic pipe wall, a temperature difference exists across the pipe wall; that is, the outside pipe wall and fluid temperature are not the same as in the case of metallic pipe. Therefore, the fluid temperature should be considered.

For non-metallic pipe,

$$T_{sh} = \frac{Q_{sf}}{U_p C} + T_f \quad (9)$$

where

- Q_{sf} is the upper tolerance trace heater output (W/m);
 T_f is the fluid temperature (°C).