CHAPTER B6

HEAT-TRACING OF PIPING SYSTEMS

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The term *heat-tracing* refers to the continuous or intermittent application of heat to a pipeline or vessel in order to replace heat loss to ambient.[1] The major uses of heat-tracing include freeze protection, thawing, maintenance of fluids at process temperature (or at pumping viscosities), prevention of fluid component separation, and prevention of gas condensation.

The following examples are typical of the diversity of heat-tracing applications: freeze protection of piped water; transfer of molten process chemicals such as phosphoric acid, sulfur, and *p*-xylene; low-viscosity maintenance of pumped fluids including petroleum products, vegetable oils and syrups, polymeric and resinous materials, and aqueous concentrates and slurries; avoidance of condensation and subsequent improper burning of fuel gas in refineries; preventing moisture from condensing out of piped natural gas; preventing freezing of control valves and compressor damage; elimination of pipeline corrosion due to wet hydrogen sulfide resulting from condensed moisture.[2]

Heat-tracing may be avoided in situations where heat loss to the environment can be effectively minimized. In cold climates or areas with severe winters, water pipes are often buried below the frost line. Alternatively, they may be kept from freezing by running them through heated buildings.[3]

In cases where flow is intermittent, tracing might be avoided by designing a self-draining system such as those used for steam condensate returns. Pipes may also be cleared after use by means of compressed air, steam, or solvent flushing or "pigging." The self-draining method is suitable only for infrequently used pipes due to the high labor costs involved in cleaning and the potential cost and scope of repair, should a pipe not empty properly.[4]

A third approach in the avoidance of tracing is to design for 100 percent flow. This practice is not recommended since equipment breakdown or process interruption may result in an irreversible drop in the temperature of the piped fluid.

TYPES OF HEAT-TRACING SYSTEMS

Heat-tracing systems can be divided into two broad classes, electric and fluid. Fluid heat-tracing systems utilize heating media at elevated temperatures to transfer heat to a pipeline. The fluid is usually contained in a tube or a small pipe attached to the pipe being traced. If steam is the tracing fluid, the condensate is either returned to the boiler or dumped. If an organic heat-transfer fluid is employed, it is returned to a heat exchanger for reheating and recirculation. In general, heating of tracing fluids can be provided by waste heat from a process stream, burning of fossil fuels, steam, or electricity.

Electric heat-tracing systems convert electric power to heat and transfer it to the pipe and its contained fluid. The majority of commercial electric heat-tracing systems in use today are of the resistive type and take the form of cables placed on the pipe. When current flows through the resistive elements, heat is produced in proportion to the square of the current and the resistance of the elements to current flow. Other specialized electric tracing systems make use of impedance, induction, and skin conduction effects to generate and transfer heat.

Table B6.1 lists the operating and exposure temperatures and the principal characteristics of the different types of heat tracing.

FLUID HEAT-TRACING

Steam

A number of desirable features made steam the original heat-tracing system of choice to maintain process temperature and provide freeze protection. Steam's high latent heat from vaporization is ideal for heat-transfer applications. Only a small quantity is required for a large heating load; and it can heat a line quickly, condense at constant temperature, and flow to the point of use without pumping. Steam is universally available and nontoxic.[5]

Today, energy efficiency and minimization of expensive labor are priority considerations in selecting an economical heat-tracing system. With the advent of highly reliable electric heat-tracing, the popularity of steam heat-tracing is declining.

Steam is more expensive to install and maintain than electric resistance heaters. Periodic leaks and failed steam traps in a steam-traced system waste energy and demand additional labor costs for repair and replacement. In addition, a single steam tracer provides 2 to 10 times more heat than most applications require. By contrast, electric tracing systems provide better temperature control and much more efficient utilization of energy. This means that even though the cost per unit energy is lower for steam, total energy costs for electric tracing are usually significantly lower.[6]

In most heat-tracing applications, saturated steam is supplied at pressures of 30 to 150 psig (210 to 1035 kPa) (298°F/147°C and 367°F/186°C). The ability to

TABLE B6.1 Comparison of Heat-Tracing Methods

Heat-tracing method	Max. operational temp.	Max. exposure temp.	Advantages	Disadvantages
		Heat transfer fluids		
Steam	400°F (204°C)	None	Takes advantage of waste steam, explosion environment safe, high heat-transfer rates	Nonuniform heat distribution; expensive to install and maintain; imprecise temperature control; wastes energy
Organics	500–750°F (260–400°C)	None	Moderate temperature control, wide temperature range, low freezing temperatures	Relatively expensive; needs a circulating system; leaks can be hazardous
Glycols	250°F (121°C)	325°F (160°C)	Moderate temperature control; depresses freezing point, providing protection against freezing when not in use; lower operating cost than steam	Relatively expensive (glycols are cheaper than heat process fluids); high installed costs; needs a circulating system; leaks can be hazardous
		Electric		
Self-regulating	150–300°F (65–149°C)	185–420°F (85–215°C)	Will not burn out—most reliable electric heating cable; energy efficient	Limited temperature range
MI cable	1190°F (590°C)	1500°F (800°C)	Rugged; capable of high temperature and high power	Difficult to field cut; a break in the cable causes an open circuit; should not be crossed over itself; can be damaged by moisture penetration
Zone	150–400°F (65–204°C)	250–1000°F (121–538°C)	Can be field cut; if a heating element fails, circuit is maintained	Relatively fragile; can self-destruct from its own heat; can burn out if crossed over itself
Skin effect	400°F (204°C)	450°F (232°C)	Simple components; rugged; needs relatively few energy inputs; can be part of a prefabricated insulated pipe bundle	Impractical for applications less than 5000 ft long; design is complex
Impedance	Up to failure of supply cable and connections	None	High heat-transfer rates and close temp. control; high temp. capability, heating structure; element cannot burn out	Expensive custom design; entire pipeline must be electrically isolated from the support
Inductance	Up to Curie point	None	High-temperature capability; high heat-transfer rates	Very expensive; difficult custom design, not commercially exploited

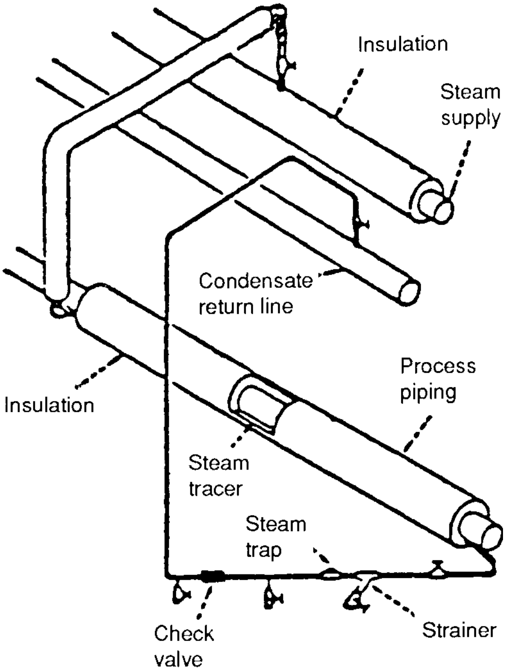


FIGURE B6.1 Typical components of a steam-tracing system. (*I. P. Kohli, "Steam Tracing of Pipelines,"* Chem. Eng., *March 26, 1979, p. 158, Fig. 1.*)

continuously remove condensate via a steam trap assembly allows the steam tracer to provide a constant-temperature source of heat.

The overwhelming majority of steam-traced piping systems employ external tracing. Straight runs of the steam pipe or tubes are attached to the pipe, and the entire assembly is covered with preformed sectional insulation (see Fig. B6.1). Valves, fittings, and instruments are *heat sinks* (system components of large surface area and exposed metal surfaces to which system heat will flow and be lost to the environment); and to deliver the requisite amount of heat, several loops of the tracing tube are coiled around them before being covered with insulation. This configuration helps reduce *tailing*, i.e., the tendency of steam to lose heat and condense along the line with loss of pressure (see Fig. B6.2).

In the majority of applications such as freeze prevention and viscosity maintenance in smaller-diameter pipes, a single tracer provides more than the required heat. However, for processes requiring greater heat input, the heat-transfer characteristics of steam tracers can be significantly improved by placing heat-transfer cement between the trace and the pipeline, greatly increasing the amount of surface for conductive heat transfer.[7] Temperatures of steam-tracing systems can vary by as much as +10°F (6°C) between underground pipelines and +20°F (11°C) for pipelines running aboveground. The inability to achieve precise temperature control is attributed to three factors operating in tandem.[8]

1. Saturated steam is delivered at the desired pressure by means of a pressure-

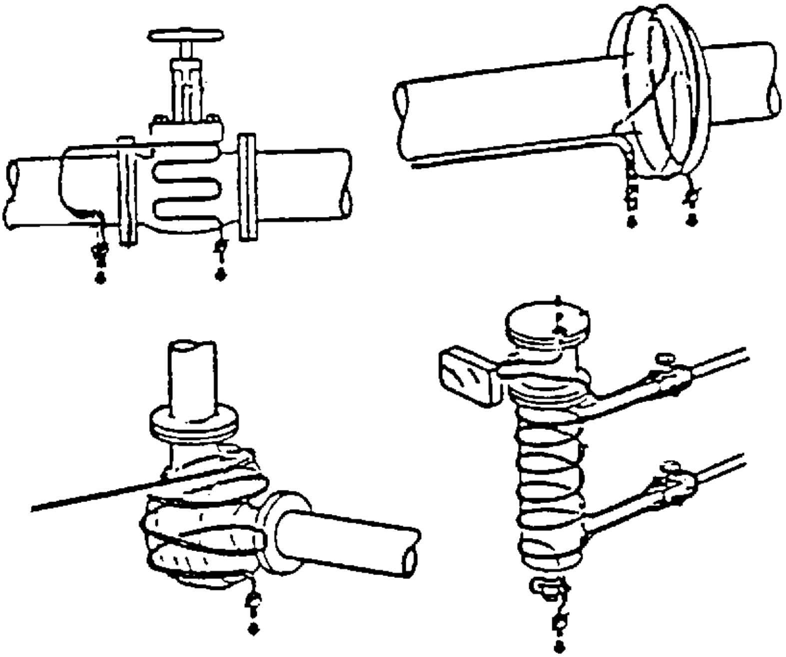


FIGURE B6.2 "Coiling" arrangement for tracing valves, flanges, casings, and instruments. Coils act as expansion joints for steam tracing systems. (*I. P. Kohli, "Steam Tracing of Pipelines,"* Chem. Eng., *March 26, 1979, p. 159, Fig. 3.*)

reducing valve. As the pressure is reduced, the saturated steam becomes superheated. The excess heat is rapidly dissipated in the system.

2. Uneven contact between the steam tracer and process pipe produces an uneven distribution of temperature. This effect becomes more significant as the temperature difference between pipe and tracer increases. When the steam becomes superheated, the temperature difference reaches a maximum.
3. Tailing also affects the temperature of the surrounding steam.

A more precise control of steam tracer temperature can be achieved by the use of steam jacketing (see Fig. B6.3) or temperature-sensitive steam valves. However, these methods are rarely used as they provide a level of temperature control inferior to that of electric heat-tracing, and at a significantly greater cost.

Circulating Media

Circulating media are the most expensive heat-tracing systems and are specified for special-process or ambient conditions (see Table B6.1 and Ref. 9). The virtue of circulating fluids is the ability to provide protection and reasonable control at temperatures above and below those achievable with steam-tracing. Circulating media systems can be separated into two classes; oils and organic heat-transfer

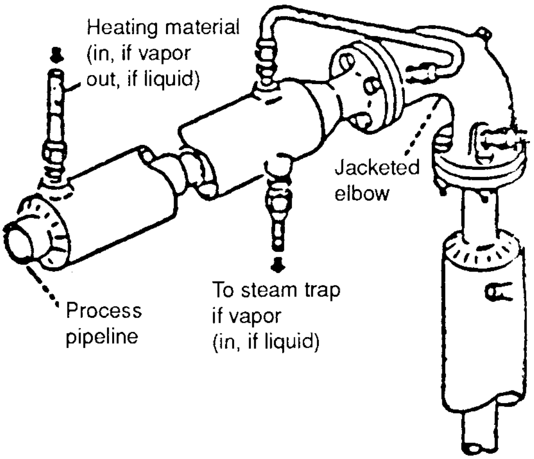


FIGURE B6.3 Steam jacketing is expensive and employed only in special high-heat-demand situations. (*I. P. Kohli, "Steam Tracing of Pipelines,"* Chem. Eng., *March 26, 1979, p. 159, Fig. 2.*)

fluids suitable for high-temperature applications, and glycols with antifreeze properties that make them especially useful in cold climates, where they will not freeze even when used intermittently.

ELECTRIC RESISTANCE HEAT-TRACING

Introduction

Significant commercial use of electric heat-tracing began to take hold in the 1950s. Electric heat-tracing served as a visible alternative in situations where steam could not be used or was impractical. Typical early applications included the electric tracing of transfer lines for oil, asphalt, and waxes. Electric tracing proved especially useful for long runs of pipe. [Steam tracers are generally limited to runs of 100 to 200 ft (30 to 60 m). Tracing long or multiple pipe runs with steam can significantly increase both tracing complexity and cost.]

At the outset, hardware had to be adapted from other resistance heating applications. Lead-sheathed soil-heating cable was used extensively for waterline freeze protection while longer runs of pipe were traced with mineral-insulated copper-sheathed cable. For higher-temperature service, tubular heaters (normally used for immersion and clamp-on applications) were converted for pipe tracing, and controllers were adapted from furnaces and consumer appliances in order to control temperature.

Self-Regulating Heaters

Since their introduction in 1971, self-regulating heaters have become the most popular form of electric heat-tracing and are currently offered by most major vendors of industrial heat-tracing. Self-regulating heat-tracing has an advantage with respect to other heat-tracing products because this technology eliminates the possibility of heater burnout due to the inability to dissipate internally generated heat—the most common cause of heater failure (Fig. B6.4).

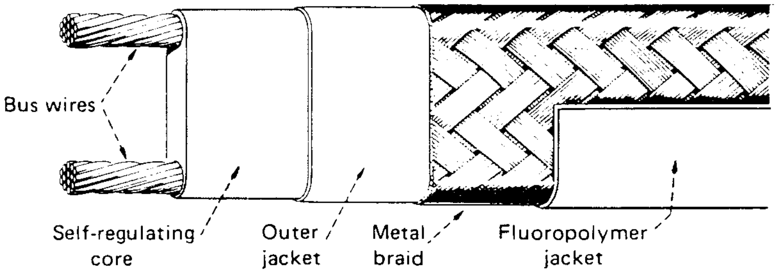


FIGURE B6.4 Components of a self-regulating parallel resistance heat-tracer. (*Chet Sandberg,* Electrical Heat Tracing Systems for Use in Pulp and Paper Plants; Considerations for the 1990's. *ISA Pulp and Paper Industries Division Symposium (in conjunction with TAPPE), Nashville, TN, March 1993.*)

Self-regulating tracers are usually provided in the form of a heater strip consisting of two parallel 20 to 10 American wire gauge (AWG) bus wires embedded in a conductive polymer core, which serves as the heating element and over which a polymeric insulator is extruded. The entire assembly is then covered with a metal braid to provide grounding and additional mechanical protection. Another polymer jacket can be added (see Fig. B6.4). The heater core consists of carbon particles embedded in a polymer matrix. Heat is generated by resistance to current flowing through the conductive polymer heating element. As the temperature of the conductive core increases, so does the electric resistance. The result is a diminishing output of heat for each successive increment of temperature elevation. Since power output is a function of temperature at any location in the element, the conductive core behaves as a temperature-sensitive rheostat guarding against low- as well as high-temperature failure (see Figs. B6.5 and B6.6).

Self-regulating tracers can be cut to any desired length and field-installed within the limitations of the voltage drop on the bus wires. They have good impact resistance and are routinely handled in the field. The self-regulating feature pro-

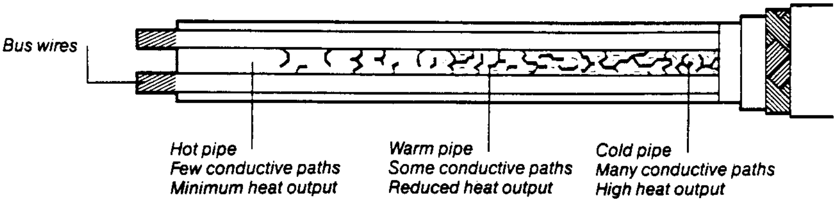


FIGURE B6.5 Relationship of resistive properties to changes in polymer structure with temperature in the conductive core of a self-regulating parallel resistance heat-tracing tape. (*Karen Henry,* Introduction to Heat Tracing, *Cold Regions Research and Engineering Lab, Report No. CRREL-TD-86-1, June 1986, p. 13.*)

vides a tremendous boost to operational reliability while cutting installation, maintenance, and energy costs. It also adds a dimension of safety unavailable with any other form of electric resistance tracing product because the heater cannot be destroyed by its own heat output.

The only serious drawback of self-regulating tracers is the upper limit on operating temperatures, 366°F (186°C) for constant exposure and 420°F (215°C) for intermittent exposure.[13] Self-regulating tracers can fail as a result of exposure to excess heat from the piped fluid or from steam cleaning. For this reason, the tracer must be selected to conform to actual process conditions.

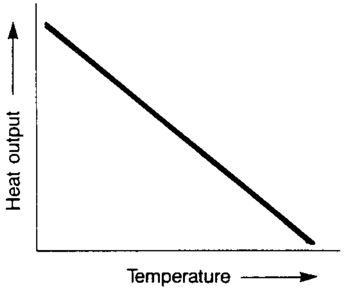


FIGURE B6.6 Graph of resistance versus temperature for a self-regulating parallel resistance heat-tracer. (*G. R. Dixon*, Steam versus Electric Process Heat Tracing. *Mississippi Department of Energy and Transportation Annual Conference, April 22–24, 1987, p. 5, Fig. 4.*)

Zone Heaters

First introduced in 1971, zone heaters were initially the most popular form of parallel resistance heaters; and by the mid-1970s, they were being used in a large percentage of electric heat-tracing applications. Since that time, they have been increasingly replaced by self-regulating heaters.

A typical zone heater consists of two insulated bus wires wrapped with a small-gauge (38 to 41 AWG) nichrome heating wire, covered with polymer insulation and sheathed in a metallic braid covered with an optional polymer jacket. The heating wire is connected to alternate bus wires at nodes every 1 to 4 ft (0.3 to 1.2 m), and the distance between connections constitutes a (heating) zone.[14,15,16] Heat is generated by current flowing between the bus wires through the heating wire (see Fig. B6.7).

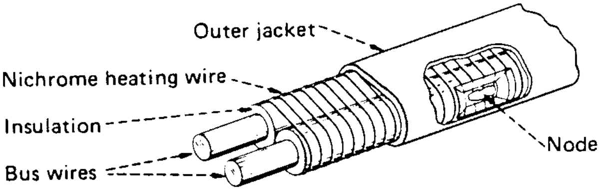


FIGURE B6.7 Components of a zone-type parallel resistance heat-tracer. (*G. B. Dixon*, Steam versus Electric Process Heat Tracing, *Mississippi Department of Energy and Transportation Annual Conference, April 22–24, 1987, p. 5, Fig. 5.*)

The parallel circuit configuration of zone heaters means that output is independent of cable length and that systems can be designed and adapted by purchasing cables of a specific wattage which are cut to length in the field. (It is important to remember that the length of cable between the cut and the nearest node will not receive power and should not be depended upon for heater service.) As a result,

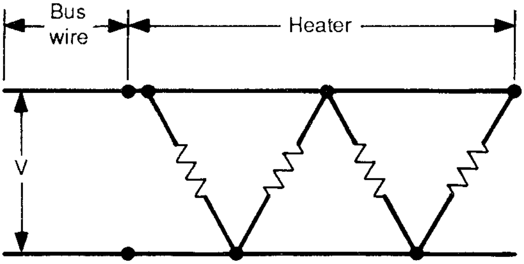


FIGURE B6.8 Simplified circuit diagram for a zone-type parallel resistance heater. (*Karen Henry*, Introduction to Heat Tracing. *Cold Regions Research and Engineering Lab, Report No. CRREL-TD-86-1, June 1986, p. 8, Fig. 3c.*)

design and installation costs are significantly reduced.[17] Zone heaters use standard voltages, and their parallel circuitry preserves system function in the event of individual heater element failure (see Fig. B6.8)—an important advantage over series circuits (see Fig. B6.9).[18]

Zone heaters use thinner resistive wires than series heaters and are more susceptible to damage from impact.[19,20,21] Fiberglass-insulated cables are available with an exposure temperature up to 1000°F (538°C), but they are susceptible to moisture.

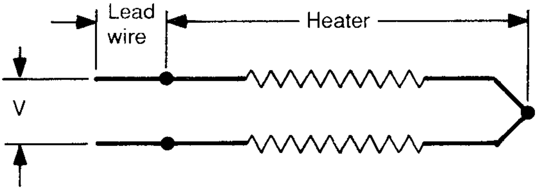


FIGURE B6.9 Simplified circuit diagram for a series-type resistance heater. (*Karen Henry*, Introduction to Heat Tracing. *Cold Regions Research and Engineering Lab, Report No. CRREL-TD-86-1, June 1986, p. 8, Fig. 3a.*)

The addition of a fluoropolymer jacket for moisture protection reduces the exposure temperature rating to 545°F (285°C). Perhaps the biggest drawback of zone heaters is their susceptibility to burnout. With their combination of constant wattage and polymer insulation, zone heaters are vulnerable to destruction from self-generated overheating.[22] As with all constant-wattage heaters, zone heaters to be used in hazardous (classified) areas require factory calculations to determine if the system conforms to the prescribed T rating (see the later section ‘‘Area Classification’’).

Mineral-Insulated Cable (Constant-Wattage Series) Heater

Mineral-insulated (*MI*) *cable* was introduced in the early 1950s as an electric powered alternative to steam and liquid heat-tracing.[23] MI cable is a constant-wattage, series resistance heater in which the entire circuit acts as a continuous heating element.

Heat is generated by current flowing through a nichrome, copper, or other metal

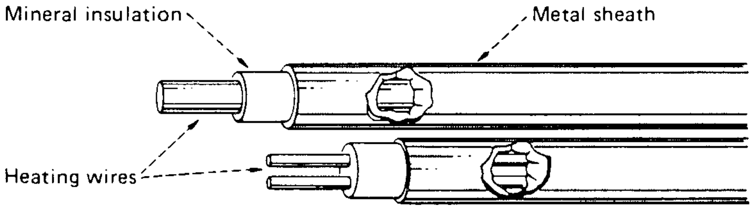


FIGURE B6.10 Components of mineral-insulated heat-tracing cable. (*G. B. Dixon*, Steam versus Electric Process Heat Tracing, *Mississippi Department of Energy and Transportation Annual Conference, April 22–24, 1987, p. 4, Fig. 2.*)

conductor, insulated with magnesium oxide and encapsulated in an outer metallic sheath of copper, stainless steel, Inconel, or other suitable metals (see Fig. B6.10).[24]

MI cable is capable of carrying high heating loads. Given the proper conductor and sheath alloys, it can be used in applications up to 1500°F (800°C).[25]

Its high impact resistance and general ruggedness allow it to stand up to the rough handling in the field. Circuits usually are factory-fabricated to length prior to installation, which can be a source of problems when piping changes are made since cables are difficult to modify in the field. Field fabrication of circuits is sufficiently complex that the training of installation personnel should be supervised by a trained factory technician.[26,27] MI cable system circuits must be individually designed, or variable-voltage controls must be provided to set circuit parameters. Voltage control may also be required for short lengths due to the low resistance.[28]

As with all series circuits, a single break in the cable causes the entire system to fail (breaks in the outer sheathing can cause failure due to absorption of moisture and subsequent loss of insulating properties).[29,30] Another disadvantage of MI cable is the risk of overheating from excessive currents or poor thermal dissipation. Hazardous-area installations must be factory-calculated to ensure conformance with the proper *T* rating (see later section ‘‘Area Classification’’).

Series Resistance Polymer-Insulated Cable

Polymer-insulated series resistance cables can be used with various conductor materials. Nichrome is suitable for short circuits, but the length must be either predetermined to suit the available voltage or field-cut and provided with a variable-voltage supply. Conductors such as copper offer a measure of self-limiting heater properties, since their resistance increases with temperature. This allows greater latitude of use, and copper conductors with their 600-V limitation and relatively low cost (even with the mandatory metallic braid and optional overjacket) are especially favored for long-line applications with this type of heater.

The circuits must be designed and controlled to minimize high temperature, because a failure at one spot disables the complete circuit. The possibility of catastrophic failure (series circuit) due to overheating and melting of the polymer insulation puts this type of tracing in unfavorable competition with parallel resistance heat-tracing systems, which dominate in the low- to moderate-temperature application ranges.

SKIN EFFECT TRACING

Skin effect systems are primarily applicable to the tracing of long pipelines. The *skin effect* is based on the tendency of an alternating current to flow in the layers near the surface (skin) of a current-carrying ferromagnetic conductor (see Fig. B6.11). In a typical skin effect tracer, the heating element is a carbon-steel pipe of small diameter welded to the fluid-carrying pipeline to be traced. Running through the heat tube is an insulated, low-resistance copper wire. The alternating magnetic field created by this alternating-current-carrying conductor causes the return current in the small heat tube to be concentrated toward the inner wall of the tube. This phenomenon is called the *proximity effect*. Because almost no current flows on the outer surface of the heat tube, there is no measurable potential there and the entire piping system can be grounded at any number of points.[31,32]

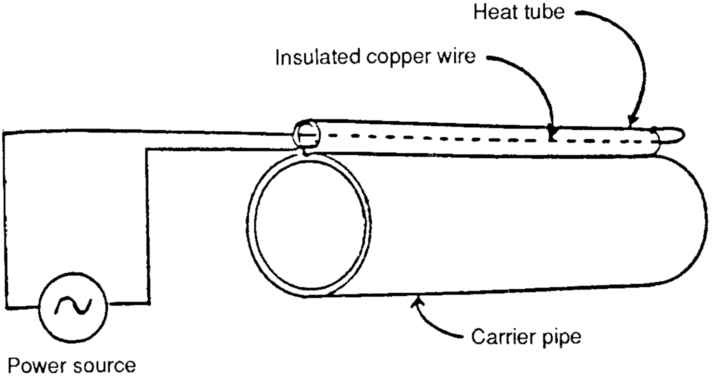


FIGURE B6.11 Components and electrical flow in skin effect heat-tracing (*N. B. Carson*, A New Method for Heat Tracing Long Pipelines, *ASME, Petroleum Mechanical Engineering Conference, Dallas, Texas, September 1974, p. 1, Fig. 3.*)

The requirement for custom system design makes skin effect systems costly, notwithstanding the ability to make use of ordinary low-cost materials, including prefabricated components and standard construction techniques. The method maintains a low-temperature difference between fluid and tube circuit wall (18°F/10°C),[33] is considered reliable, and is easy to repair. Single-circuit envelopes of up to 25,000 ft (7500 m) are feasible with supply voltages of 3000 V. Higher supply voltages make even longer circuits possible.[34] One reference reports a single power station capable of supplying service up to 30 mi (48 km) of pipeline.[35] On the other hand, Carson qualifies this with a practical limitation of 10 mi (16 km), since above the 5-kV supply required for a line of this length, cable and switchgear costs become an increasing consideration.[36] This seems to be confirmed by Ando and Takki,[37] who report the construction of a 68-mi (108-km) skin effect heat-tracing system powered by 12 substations with a transformer voltage of 13,800 V.[37]

Skin effect heat-tracing is generally not cost-effective for pipelines shorter than 5000 ft (1500 m),[38] its upper temperature limit of approximately 400°F (204°C) is set by the maximum exposure temperature of the conducting wire insulation,[39] and the method is not adaptable for complex piping. Installations cannot be modified, and the complete system fails with a single line break.

IMPEDANCE HEAT-TRACING

In impedance heating, the pipe itself becomes the heating element. The generation of heat is produced by resistance to current flow (see Fig. B6.12).[40] Impedance heat-tracing has the ability to reach very high operating temperatures, limited only by the design and contents of the piping system. Since the pipe is the heating element, it is the supply cable and connections which can be vulnerable to burnout.[41] This technique has high heat-transfer rates and uniform heat distribution and provides excellent temperature control at the control point, using any one of several automatic control methods.[42,43]

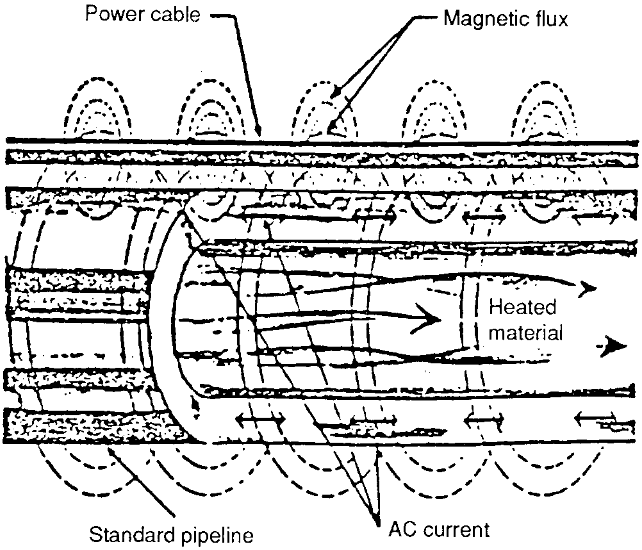


FIGURE B6.12 Components and electrical and magnetic interaction in impedance heat-tracing. (*George Koester, II, "Pipe Heat Tracing with Electric Impedance Heating,"* Plant Engineering, *vol. 32, no. 24, November 23, 1978, p. 113, Fig. 1.*)

Impedance tracing is costly and has limited application. Systems are almost exclusively vendor-designed, and the engineering can become complicated, especially in attempting to achieve an electrical balance in piping systems with multiple branches. Because significant current flows through the pipe, the entire pipeline must be electrically isolated from the support structure and shielded from personnel contact. As a precaution, impedance-traced pipelines are normally operated at 30 V or less.[44] Voltages at 80 V are allowed if ground fault protection is supplied.

INDUCTION HEATING

Induction heat-tracing uses a metallic pipeline as a heating element by placing it in the magnetic field of an alternating-current source. Low-resistance wire is wound around a conductive pipeline or vessel, and the alternating current flowing through the coils generates a rapidly changing magnetic field that induces eddy currents and hysteresis losses in the pipeline wall.[45] Induction heating has been most frequently employed for melting metals[46] and most likely would be considered for high-temperature, high-power heat-tracing applications. The absence of thermal resistance between heat source and pipeline allows very rapid heating. Present systems would involve considerable expense and custom design and would require power inputs at short intervals along the pipeline. Induction methods do not easily lend themselves to the production of uniform heating, and IEEE rates the method as providing only moderate system efficiency.[47]

SELECTION CRITERIA FOR TRACING SYSTEMS

Assuming that methods for avoiding the need for tracing have been considered and rejected, the first step in matching the heat-tracing to the piping system requires an analysis of fundamentals. These include the type of application, suitability and relative cost of different types of heat-tracing, availability of steam and/or electricity, amount of heat loss which must be made up, requirements for temperature control, and classification of the traced area as a hazardous or ordinary environment due to the presence of flammable substances.

AREA CLASSIFICATION

Areas are classified according to their potential fire hazard as defined by Articles 500 to 505 of the National Electrical Code (NEC).[48] [In industrial applications, verification that electric components meet NEC hazardous-area requirements is issued by a nationally recognized testing laboratory (NRTL).] Under this system, there are classified and unclassified (ordinary) areas. Hazardous areas have two different classification systems, the old class/division method and the new zone system. The zone system has been used in Europe for many years and is now being included in the International Electrotechnical Committee (IEC) specifications.

The old Class/Division system rates locations by class, division, and group. The area class determines the category of combustible atmosphere: flammable gases, vapors, or liquids (Class I); combustible dust (Class II); and combustible fibers (Class III). The division indicates the likelihood of a hazard to be present under different conditions. Hazardous atmospheres with similar combustion properties are listed in the same group.

To ensure that the heat-tracing system selected will operate safely in a hazardous environment, it must also be classified according to its NEC temperature identification number, or *T* rating.[49] The NEC specifies that the temperature of the exposed surface of the (electric) equipment not be in excess of 80 percent of the ignition temperature of the combustible atmosphere.

The Zone System offers more methods of protection of areas from both equipment failure and excessive temperatures. The *T* rating system is used, although there are not as many *T* ratings in the IEC system. The available ones, however, match those of the NEC exactly. The zone system has the possibility of being less expensive to install in some instances, and that is its attraction, especially on a worldwide design basis.

By comparing the *T* rating to the area classification, an assessment can be made as to heater eligibility for a particular piping system. See the later section ‘‘Design Considerations’’ for a further discussion of *T* ratings and sheath temperature calculations. For a more detailed explanation of classes and zones, see Ref. 59.

ENVIRONMENTAL CONSIDERATIONS

Environmental factors include whether the area is dry or wet, moderately or severely corrosive or noncorrosive, and whether the tracing will experience rough handling or mechanical abuse during installation, operation, or maintenance. These considerations are primarily related to the performance of electric heat tracers. Electric heaters exposed to any of the environmental stresses listed above must be protected accordingly: A metal sheath of a material is able to withstand the corrosive agent for MI cable; a braided sheath covered by a polymer jacket formulated for protection from particular classes of corrosives is required for polymer-insulated types of heating cables (jacket of modified polyolefin for resistance to moisture and inorganic chemical agents; fluoropolymer for resistance to organic chemicals). The heater must be rated to withstand anticipated maximum exposure temperatures.

HEATER RELIABILITY AND CONSEQUENCE OF FAILURE

In addition to selection of a system with the appropriate *T* rating, environmental protection, and proper installation, a heat-tracing system must be evaluated in terms of the risk and consequence of failure. Savings in front-end costs may not be justified if the failure of a tracing system incurs the far larger expense of disrupting a process which depends on maintaining an acceptable temperature in the traced piping or requires removal and replacement of the thermal insulation and tracing system.

Steam tracing systems have high maintenance costs, but system failure is generally not a concern. The major cause of electric tracing system failure is compromised insulation. Zone heaters and self-regulating heaters have parallel circuits. Failure of a single heating element does not bring down the entire system, and repairs can be made in the field. The series circuitry of MI and polymer-insulated cable allows no such flexibility. A single failure brings the entire system down. MI and polymer-insulated cable is difficult to field-repair, requiring the services of a trained technician. See the section ‘‘Types of Heat-Tracing Systems’’ for detailed characteristics of different heat-tracing systems.

TRACING OPTIONS FOR DIFFERENT TEMPERATURE RANGES

Table B6.1 classifies heat-tracing technologies according to operating temperature ranges and maximum exposure temperature.

TABLE B6.2 Selected Examples of Time versus Temperature Loss in an Insulated Pipe

Pipe fluid	Light fuel oil	Water
Analysis ambient temperature	Static aboveground 0°F (−18°C)	Static aboveground −20°F (−29°C)
Wind speed	20 mi/h (32.2 km/h)	20 mi/h (32.2 km/h)
Pipe	Carbon steel	Carbon steel
Nominal diameter	4 in (10 cm)	2 in (5 cm) and 0.5 in (1.25 cm)
Insulation type and thickness	Fiberglass 2 in (5 cm)	Fiberglass 1 in (2.5 cm)
Initial temperature	140°F (60°C)	50°F (10°C)
Final temperature	90°F (32°C)	32°F (0°C) frozen solid
Time to final temperature	7 h	21 h for 2 in, 4 h for 0.5 in

Note: In practice, an occasional short interruption of power will not be a serious concern in the selection of electric heat-tracing. Heat loss from a fluid-filled pipe is sufficiently slow that intermittent power outages are unlikely to cause a serious lowering of temperature.

Source: *Heat-Up/Cool Down Analysis Program*, Raychem Corp., Menlo Park, CA.

AVAILABILITY OF STEAM AND ELECTRICITY

In process plants, steam is almost universally available. And except in regions with substantially developed hydroelectric power, electricity is invariably generated from steam.

When one is considering the use of electric heat-tracing, especially in some developing countries, the reliability of the power for uninterrupted delivery, available voltages, and the consequences of outages must be evaluated. In practice, heat loss from a fluid-filled, insulated pipe is a rather slow process. It will take many times longer than the duration of an intermittent power outage to suffer a serious lowering of temperature.

For example, an aboveground NPS 2 (DN 50) in carbon-steel pipe with 1 in (25 mm) of fiberglass insulation containing static water at an initial temperature of 50°F (10°C) will take 21 h to freeze when the ambient temperature is −20°F (−29°C) (see Table B6.2). Unless power disruption is expected to be of long duration (an exceedingly rare occurrence), reliability of the power supply is not a determining consideration. One exception to this is the tracing of instrument lines. Because of their small size, instrument lines will freeze much more quickly. In the above example a 0.5-in instrument line would freeze solid in 4 h (see Table B6.2). While this is much quicker than a pipe, it is still generally less than the duration of the typical short-term power failure.

The most significant factor in a decision between steam and electric tracing is the cost of installing and operating the system, and these costs depend on factors such as the geometry of the piping system, cost of labor and energy, and local tracing practice.[50]

INSTALLED AND OPERATING COSTS

In general, installation of steam tracing is more labor-intensive (½-in copper tubing is more difficult to install than the more flexible electric cable). In high-labor-cost areas, such as Europe and North America, the expense of labor can easily offset the higher material cost of electric tracing. In areas where labor costs are considerably lower, steam may have an economic advantage. This is especially true in South America, where steam tracing predominates and the practice is well established.[52]

Since most electricity is produced from steam with about a 40 percent conversion efficiency, raw energy cost will always favor steam by a factor of 2 to 3. However, steam tracers have inherent disadvantages that usually make electric tracing more cost-effective in overall energy utilization. Maintenance costs also tend to favor electric tracing. As with installation, the maintenance cost differential between electric and steam tracing will tend to be greatest in high-priced labor markets.[53]

The above tradeoffs generally apply to both pipe tracing and the tracing of instrument lines. Because they are smaller, instrument lines require less energy, but this causes only a slight decrease in costs for both steam tracing and electric tracing. One major disadvantage steam tracing has in tracing instrument lines is that care must be taken to ensure that the steam tracer does not overheat the line. It is possible for a steam tracer to actually boil a small instrument line. This is generally not a concern with electric tracing as self-regulating heaters can be used.

TABLE B6.3 Comparison of Electric and Steam Tracing Freeze Protection Costs

Steam tracing		
Installed costs, $/ft of tracing		
Supply piping		$ 6.37
Steam tracer		9.32
Steam trap assemblies		20.33
Condensate return		5.33
Thermal insulation line	$18.65	
Thermal insulation, other	12.85	
Thermal insulation, total		31.50
Total steam tracing installation costs		$72.75
Operating costs, $/ft of tracing/yr		
Energy tracer		$1.85
Energy traps		3.33
Energy supply and return		0.76
Energy, total		5.94
Maintenance, total		1.46
Total steam tracing operating costs		$7.40
Electric tracing		
Installed costs, $/ft of tracing		
Heaters		$13.29
Motor control center		0.26
Panels		4.10
Control and distribution		13.53
Thermal insulation, total		19.58
Total cost of electric tracing		$50.76
Operating costs, $/ft of tracing/yr		
Energy, total		$0.11
Maintenance, total		1.32
Total operating cost of electric tracing		$1.43

Metric conversion: Multiply per-foot cost by 3.28 to obtain per-meter cost per year.

COMPUTER SELECTION PROGRAMS[54]

Computer programs now exist which can greatly simplify the work of determining the economics of steam versus electric heat-tracing. Many heat-tracing vendors provide user-friendly heat-tracing selection programs for use with their lines of products. Input involves supplying answers to a series of fill-in-the-blank questions covering size, diameter, and geometry of the piping to be traced; ambient and maintenance temperatures; control requirements; labor costs; and exchange rates. The program then calculates worst-case heat loss, determines the components needed to build a steam or electric tracing system to maintain the pipe at the required temperature, and calculates the associated material, installation, and operational costs for both cases.

TABLE B6.4 Comparison of Electric and Steam Tracing Process Maintenance Temperature Costs

Steam tracing		
Installed costs, $/ft of tracing		
Supply piping		$ 27.62
Steam tracer		9.30
Steam trap assemblies		79.38
Condensate return		24.98
Thermal insulation line	$17.72	
Thermal insulation, other	55.02	
Thermal insulation, total		72.74
Total steam tracing installation costs		$214.02
Operating costs, $/ft of tracing/yr		
Energy tracer		$ 3.64
Energy traps		11.02
Energy supply and return		2.12
Energy, total		$16.76
Maintenance, total		6.18
Total steam tracing operating costs		$22.96
Electric tracing		
Installed costs, $/ft of tracing		
Heaters		$30.75
Motor control center		0.44
Panels		6.65
Control and distribution		21.35
Thermal insulation, total		19.02
Total cost of electrical tracing		$78.21
Operating costs, $/ft of tracing/yr		
Energy total		$0.05
Maintenance total		1.73
Total operating cost of electrical tracing		$1.78

Metric conversion: Multiply per-foot cost by 3.28 to obtain per-meter cost per year.

Cost Comparison of Steam and Electric Tracing

In a study presented at a September 1990 meeting of the IEEE,[55] a major chemical company compared the installed and operating costs of both steam tracing and electric tracing for a freeze protection system and for a process temperature maintenance system.

An existing electric tracing system was used for the freeze protection analysis. The actual costs of installing and operating this system were compared with detailed engineering estimates of the costs of installing and operating a steam tracing system to do the same task. For the process temperature maintenance study, the costs of an existing steam tracing system were compared to detailed engineering estimates of the costs of a similar self-regulating electric tracing system.

The results of this study are summarized in Tables B6.3 and B6.4, and they demonstrate that the electric tracing system is less costly to install and operate. It is interesting to note that even if the higher energy costs for steam are disregarded, the steam systems still have higher operating costs due to the expensive maintenance required. This suggests that the availability of excess low-pressure steam is not necessarily an adequate justification to select a steam tracing system instead of an electric tracing system.

STEAM OR ELECTRIC TRACING: DESIGN CONSIDERATIONS

Figure B6.13 provides a flow diagram designed to assist in choosing between steam and electric tracing. In addition to the distinctions made in the first two sections

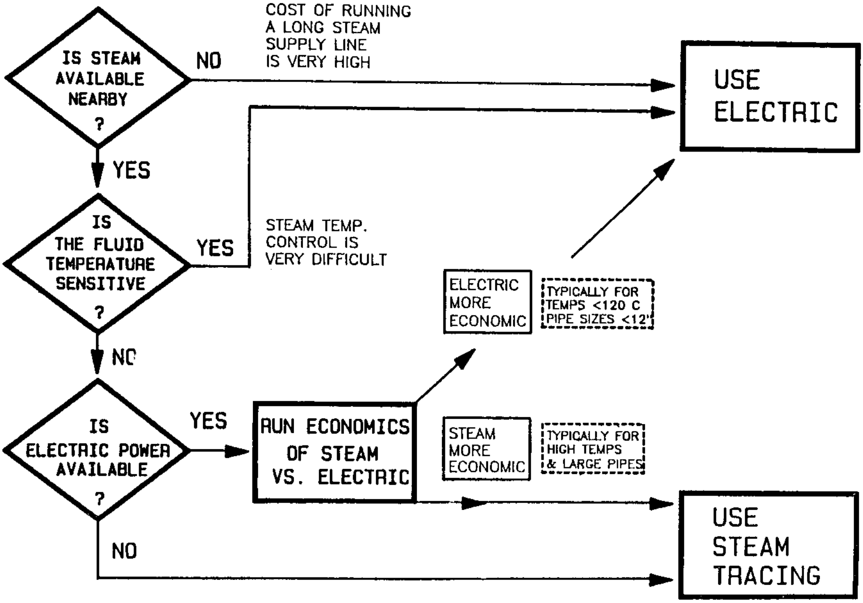


FIGURE B6.13 Steam-electric selection flow diagram. (*Raychem Corp., Menlo Park, CA.*)

of this chapter, several factors must be considered in determining the type of tracing selected:

- If steam is not available in the vicinity of the pipe being traced, the prohibitive cost of running a long steam supply line to the site usually eliminates the use of steam tracing from further consideration. By the same token, electric power must be available at the site to use electric tracing. When neither steam nor electricity is available, it is usually much cheaper to run electricity than to bring a supply of steam to a remote location.[56]
- Economics usually favor electric tracing for lines smaller than NPS 12 (DN 300) that maintain temperatures below 248°F (120°C).

ELECTRIC SYSTEM DESIGN

Electric heat-tracing is usually marketed through manufacturers' representatives. Major manufacturers of heat-tracing have representatives throughout North America and in many other parts of the world, and most are capable of designing heat-tracing systems and training plant engineers to design their own systems. Many heat-tracing manufacturers are staffed by professionals who are extremely knowledgeable in heat-tracing practice. Purchasers of heat-tracing products and systems can and often do take advantage of the design expertise and related experience that these companies make available to their customers.

Computer programs which assist in the development of heat-tracing designs are available from several manufacturers of heat-tracing products. Computer design programs allow for the rapid and comprehensive evaluation of the changes in heat loss resulting from the alteration of system variables. The ease of performing multiple computer evaluations allows more extensive exploration in design optimization, and often leads to improvements which might not be accessible if these computations had to be carried out in a less automated fashion. See Tables B6.5 and B6.6.

The following example demonstrates how a program is used in developing a heat-tracing design. In addition to calculating heat loss, these programs provide a checklist of the information required.

Data Collection

Once the information has been entered, the program will use the data to automatically select the optimum system components. While not all the requested information is always required, the use of a comprehensive inquiry form or a computer program helps ensure that all relevant data are collected.

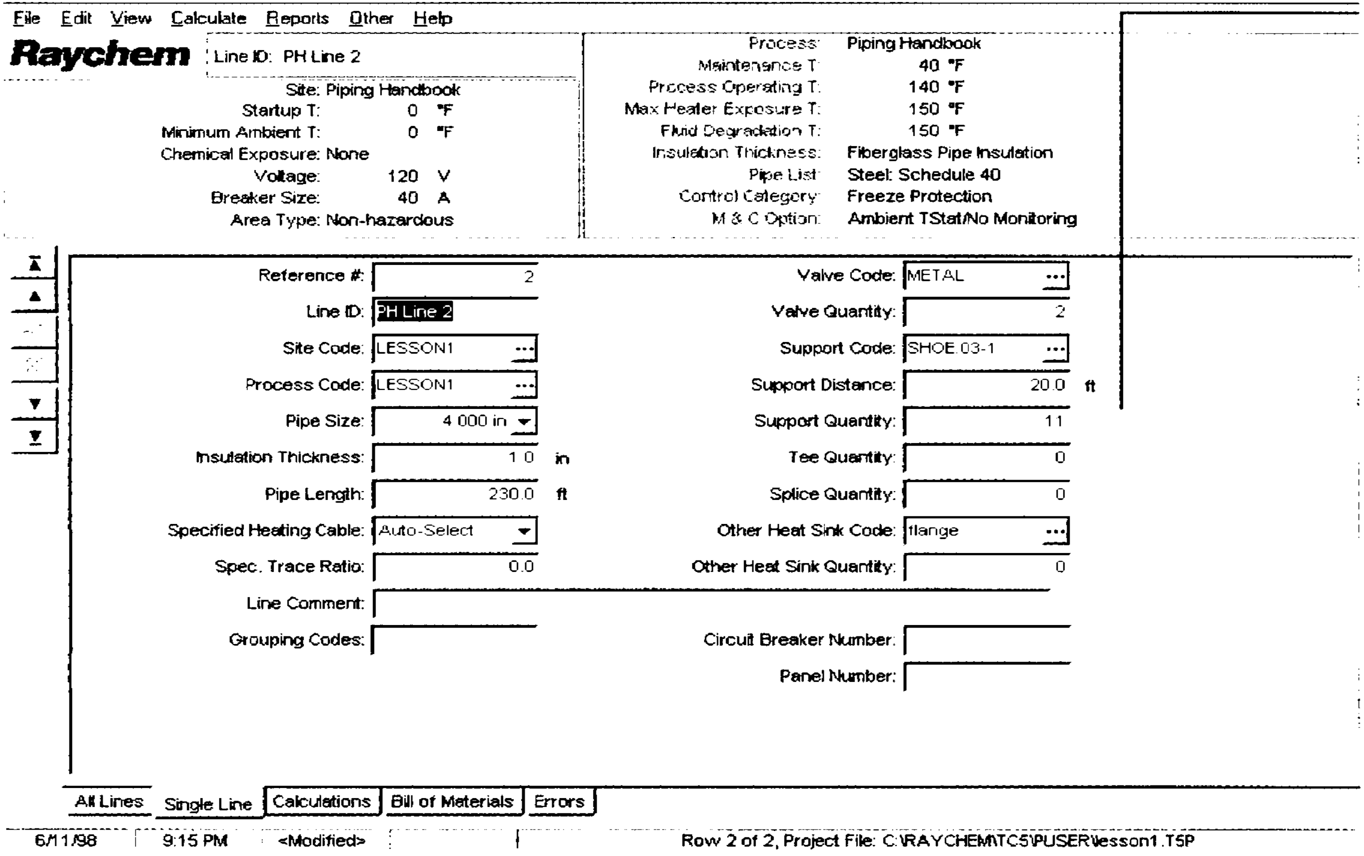
1. Thermal Data. Temperature at which the pipe is to be maintained:

$$T_m = 40^\circ\text{F} \quad (5^\circ\text{C})$$

Minimum expected ambient temperature:

$$T_a = 0^\circ\text{F} \quad (-18^\circ\text{C})$$

TABLE B6.5a Input Menu Screen Display for the Computer Program (Metric Unit Support Available in Other Unit of Measure Menu)



Line ID: PH Line 2

Site: Piping Handbook
Startup T: 0 °F
Minimum Ambient T: 0 °F
Chemical Exposure: None
Voltage: 120 V
Breaker Size: 40 A
Area Type: Non-hazardous

Process: Piping Handbook
Maintenance T: 40 °F
Process Operating T: 140 °F
Max Heater Exposure T: 150 °F
Fluid Degradation T: 150 °F
Insulation Thickness: Fiberglass Pipe Insulation
Pipe List: Steel: Schedule 40
Control Category: Freeze Protection
M & C Option: Ambient TStat/No Monitoring

Reference #: 2
Line ID: PH Line 2
Site Code: LESSON1
Process Code: LESSON1
Pipe Size: 4.000 in
Insulation Thickness: 1.0 in
Pipe Length: 230.0 ft
Specified Heating Cable: Auto-Select
Spec. Trace Ratio: 0.0
Line Comment:
Grouping Codes:

Valve Code: METAL
Valve Quantity: 2
Support Code: SHOE.03-1
Support Distance: 20.0 ft
Support Quantity: 11
Tee Quantity: 0
Splice Quantity: 0
Other Heat Sink Code: flange
Other Heat Sink Quantity: 0
Circuit Breaker Number:
Panel Number:

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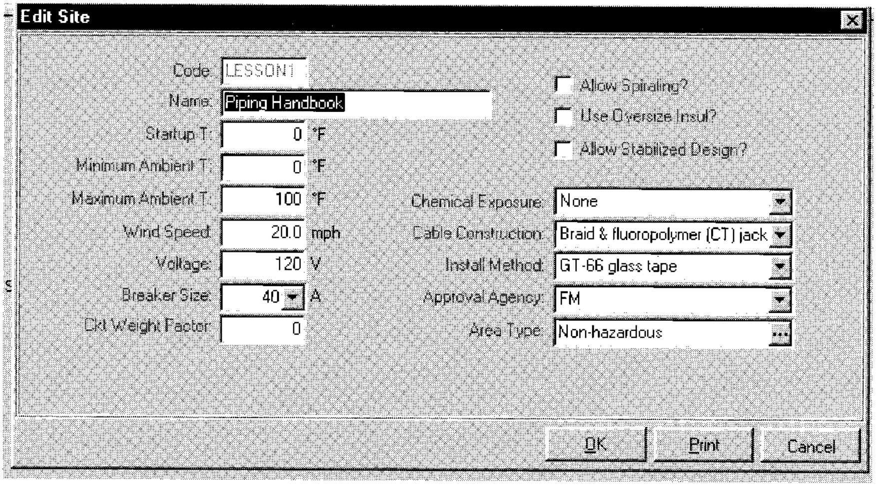
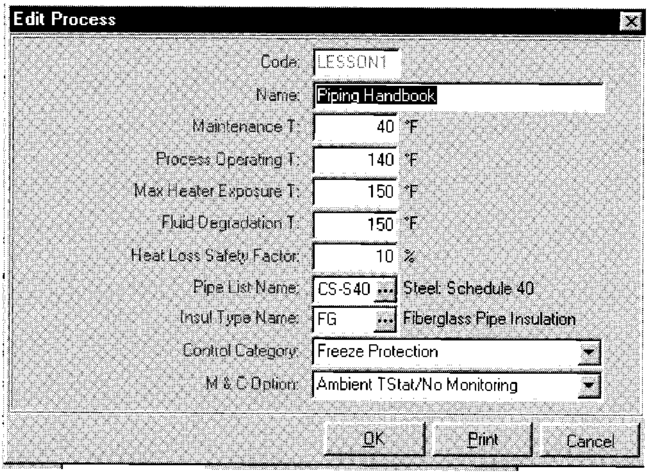
Source: *TraceCalc 5 Plus, Raychem Corporation, Menlo Park, CA, ©1998.*

TABLE B6.5b Input Menu Screen for Data Organization under SITE and PROCESS Program (Metric Unit Support Available in Other Unit of Measure Menu)



Code: LESSON1
Name: Piping Handbook
Startup T: 0 °F
Minimum Ambient T: 0 °F
Maximum Ambient T: 100 °F
Wind Speed: 20.0 mph
Voltage: 120 V
Breaker Size: 40 A
Ckt Weight Factor: 0
☐ Allow Spiraling?
☐ Use Oversize Insul?
☐ Allow Stabilized Design?
Chemical Exposure: None
Cable Construction: Braid & fluoropolymer (CT) jack
Install Method: GT-66 glass tape
Approval Agency: FM
Area Type: Non-hazardous



Code: LESSON1
Name: Piping Handbook
Maintenance T: 40 °F
Process Operating T: 140 °F
Max Heater Exposure T: 150 °F
Fluid Degradation T: 150 °F
Heat Loss Safety Factor: 10 %
Pipe List Name: CS-S40 Steel: Schedule 40
Insul Type Name: FG Fiberglass Pipe Insulation
Control Category: Freeze Protection
M & C Option: Ambient TStat/No Monitoring

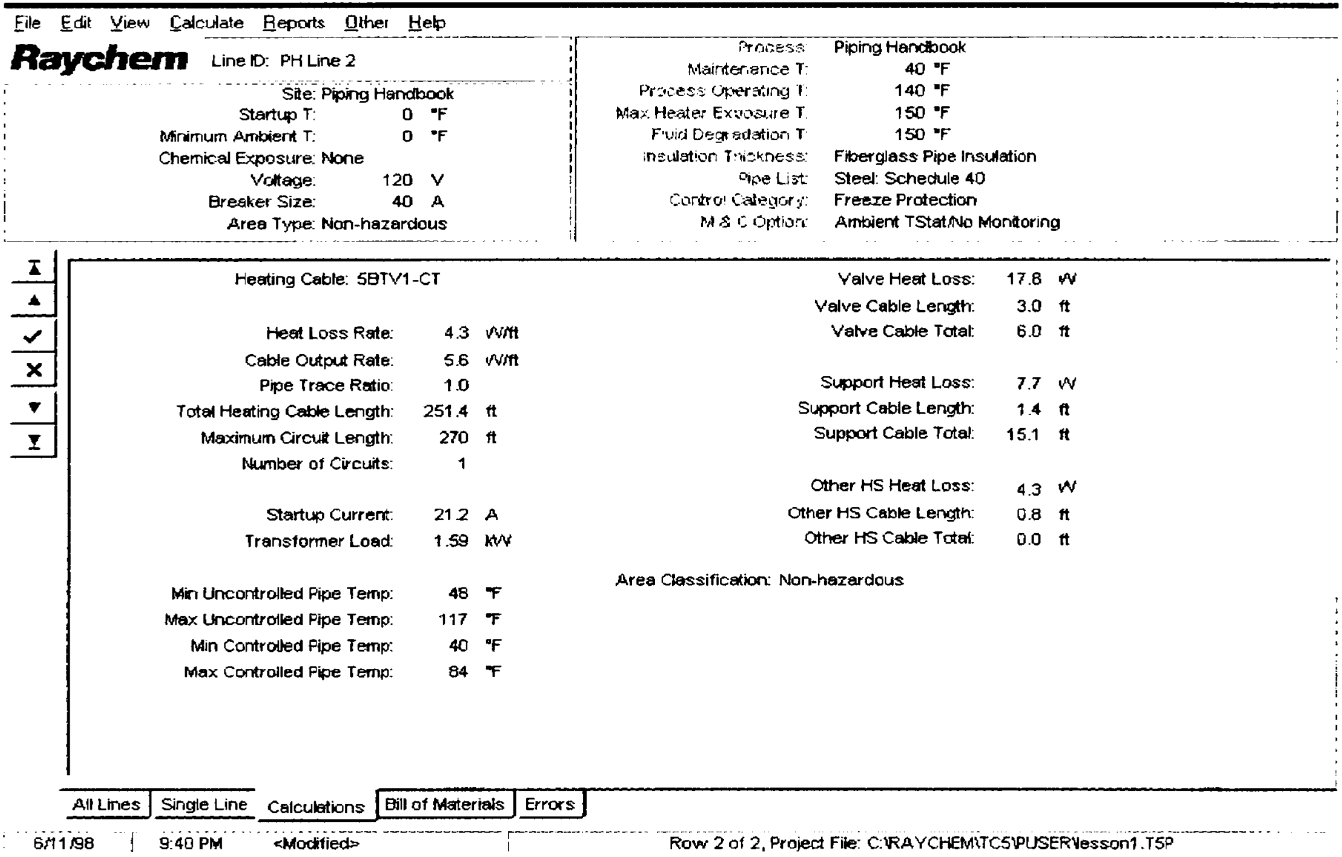
Source: *TraceCalc 5 Plus, Raychem Corporation, Menlo Park, CA, ©1998.*

Comment. Both T_m and T_a are needed to calculate the heat loss.

Maximum temperature that the heater will be exposed to due to process upsets or steam cleaning:

$$T_e = 140°\text{F} \quad (60°\text{C})$$

TABLE B6.6 Calculated Results for Data Input (Metric Unit Support Available in Other Unit of Measure Menu)



Line ID: PH Line 2

Site: Piping Handbook
Startup T: 0 °F
Minimum Ambient T: 0 °F
Chemical Exposure: None
Voltage: 120 V
Breaker Size: 40 A
Area Type: Non-hazardous

Process: Piping Handbook
Maintenance T: 40 °F
Process Operating T: 140 °F
Max Heater Exposure T: 150 °F
Fluid Degradation T: 150 °F
Insulation Thickness: Fiberglass Pipe Insulation
Pipe List: Steel: Schedule 40
Control Category: Freeze Protection
M & C Option: Ambient TStat/No Monitoring

Heating Cable: 5BTV1-CT

Heat Loss Rate: 4.3 W/ft
Cable Output Rate: 5.6 W/ft
Pipe Trace Ratio: 1.0
Total Heating Cable Length: 251.4 ft
Maximum Circuit Length: 270 ft
Number of Circuits: 1

Startup Current: 21.2 A
Transformer Load: 1.59 kW

Min Uncontrolled Pipe Temp: 48 °F
Max Uncontrolled Pipe Temp: 117 °F
Min Controlled Pipe Temp: 40 °F
Max Controlled Pipe Temp: 84 °F

Valve Heat Loss: 17.8 W
Valve Cable Length: 3.0 ft
Valve Cable Total: 6.0 ft

Support Heat Loss: 7.7 W
Support Cable Length: 1.4 ft
Support Cable Total: 15.1 ft

Other HS Heat Loss: 4.3 W
Other HS Cable Length: 0.8 ft
Other HS Cable Total: 0.0 ft

Area Classification: Non-hazardous

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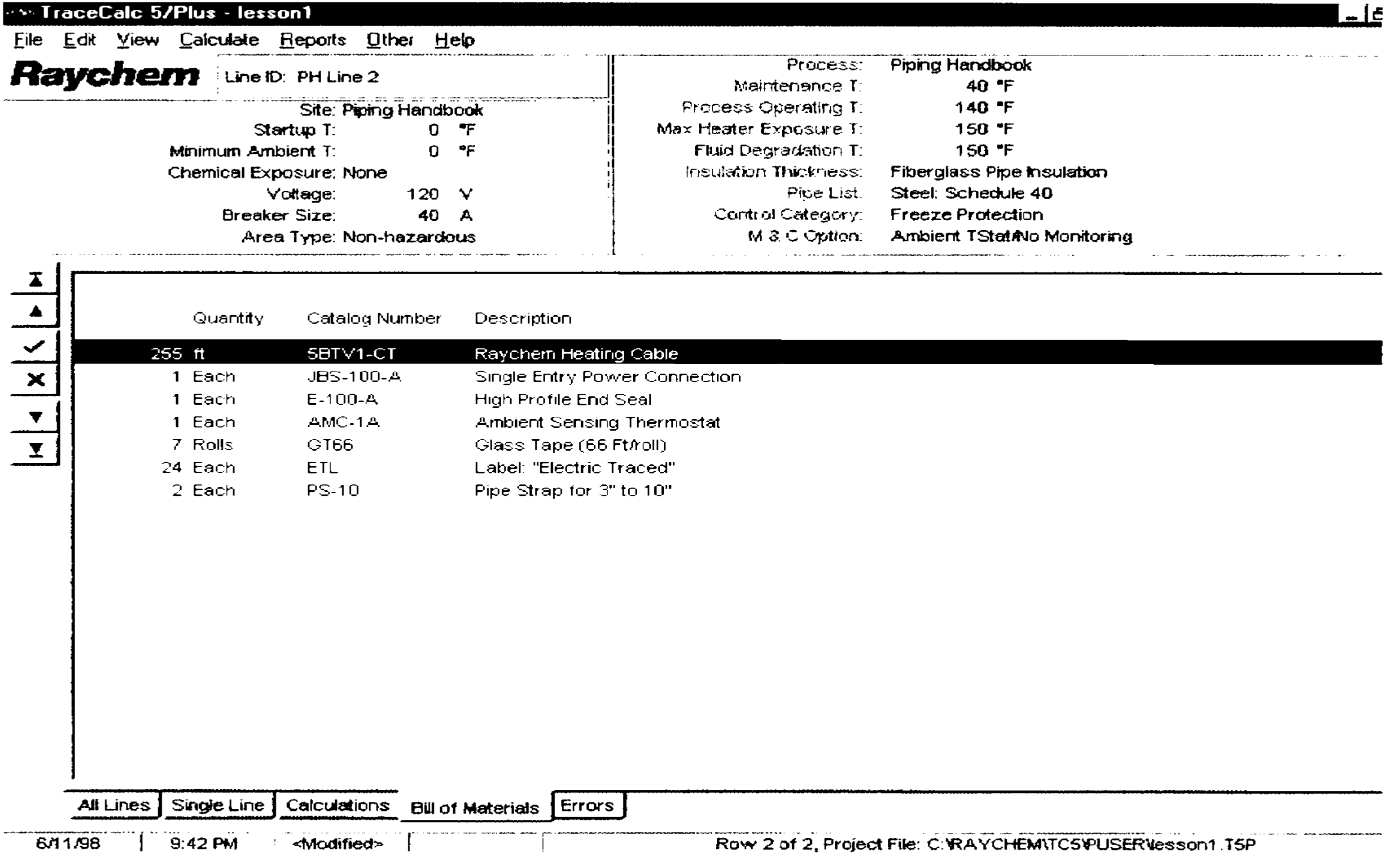
Source: *TraceCalc 5 Plus, Raychem Corporation, Menlo Park, CA, ©1998.*

TABLE B6.6 Bill of Materials for Example Input (Metric Unit Support Available in Other Unit of Measure Menu) (*Continued*)



Line ID: PH Line 2

Site: Piping Handbook
Startup T: 0 °F
Minimum Ambient T: 0 °F
Chemical Exposure: None
Voltage: 120 V
Breaker Size: 40 A
Area Type: Non-hazardous

Process: Piping Handbook
Maintenance T: 40 °F
Process Operating T: 140 °F
Max Heater Exposure T: 150 °F
Fluid Degradation T: 150 °F
Insulation Thickness: Fiberglass Pipe Insulation
Pipe List: Steel: Schedule 40
Control Category: Freeze Protection
M & C Option: Ambient TStat/No Monitoring

Quantity		Catalog Number	Description
255	ft	SBTV1-CT	Raychem Heating Cable
1	Each	JBS-100-A	Single Entry Power Connection
1	Each	E-100-A	High Profile End Seal
1	Each	AMC-1A	Ambient Sensing Thermostat
7	Rolls	GT66	Glass Tape (66 Ft/roll)
24	Each	ETL	Label: "Electric Traced"
2	Each	PS-10	Pipe Strap for 3" to 10"

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Source: *TraceCalc 5 Plus, Raychem Corporation, Menlo Park, CA, ©1998.*

Comment. The design calculation compares T_e with the maximum intermittent exposure temperature of the heater to ensure that adequate safeguards are built in to protect the heater from damage and subsequent failure. This is a serious concern in the case of heat-sensitive polymer-insulated heaters.

Process normal operating temperature:

$$T_p = 50^\circ\mathrm{F} \quad (10^\circ\mathrm{C})$$

Comment. This temperature is required to ensure that the heater selected can continuously withstand the operating temperature.

System limit temperature (imposed by process fluid, insulation, pipe material, or safety considerations):

$$T_l = 500^\circ\mathrm{F} \quad (260^\circ\mathrm{C})$$

Comment. This temperature is required to protect the rest of the system from high temperatures created by the heater. Such temperatures may be a concern where plastic pipes or temperature-sensitive fluids are to be traced. (Most heat-traced fluids are not temperature-sensitive and are transferred in steel pipe, so this variable is often of no concern in design considerations.)

2. Pipe Data and Insulation Data

Outside pipe diameter:

$$D_1 = 4 \text{ in}$$

Comment. Tables and programs are based on nominal pipe size; actual diameter is required for use in the heat-loss equation.

Outside diameter of insulated pipe:

$$D_2 = 6 \text{ in}$$

Comment. Tables and programs are based on insulation thickness equal to $(D_2 - D_1)/2$ and thermal conductivity k of the insulation material or type.

$$\mathrm{FG} = \text{fiberglass}$$

The following values are needed to calculate the pipe heat loss: D_1, D_2, and k [$= 0.25$ Btu/(h · °F · ft^2/in)].

The values of k are taken at the mean temperature between the inner and outer surfaces of the insulation. Note that the thermal conductivity of the insulation material varies with the mean temperature.

Comment. Computer programs calculate the heat loss based on the insulation type. The thermal conductivity is estimated for a mean insulation temperature; k is temperature-dependent, although the variation is small for low and moderate temperatures. Changes in k should be considered for medium- and high-temperature applications.

Pipe length:

$$L_p = 230 \text{ ft } (70 \text{ m})$$

Comment. This value is needed to estimate the length of tracing cable required.

Valves and other heat sinks: Include type and number of flanges, valves, hangers, fittings shoes, and anything that could require additional heat-tracing.

3. Service Environment Data and Classification.[57] Areas are classified on the basis of the severity of the fire and/or explosion hazard, which may be present. It is essential that the heater selected be used only in areas with classifications for which it has been approved.

Standard Area Classification

- *Ordinary area (nonhazardous)*: Areas not having explosive vapors, dust, or fibers.
- *Class I, II, III, Division 2*: Areas where explosive concentrations of vapors, dust, or fibers may be present in unusual circumstances. Special heat-tracing strip, usually equipped with a metal braid and an outer jacket, is used in these areas.
- *Class I, II, III, Division 1*: Areas where explosive concentrations of vapors, dust, or fibers may be present in usual circumstances. Measures considerably more stringent than those taken for Division 2 are required in Division 1.
- The computation example is for a Class 1, Division 2 area, a classification that is typical for the vast majority of hazardous-area designations.

Chemical Exposure

- Dry location (indoors)
- Wet location or limited exposure to aqueous inorganic chemicals
- Exposure to organic chemicals, greases, oils, or solvents

(Some types of heat-tracing can withstand corrosive inorganic chemicals, but not organics.)

Most heaters are designed for use in wet environments. Some heaters will need additional outer jackets if they are to be exposed to organic compounds.[58] The computation example is for an outdoor environment with potential exposure to organic chemicals.

4. Available Voltage. Heaters generally operate on 120 or 240 V. Most 240-V heaters are designed to operate at voltages from 208 to 277 V with some variations in power output. Generally 240-V heaters are preferred in industrial installations because they can support circuit lengths approximately twice as long as 120-V heaters can. This allows most jobs to be done with fewer circuits, considerably lowering the overall cost. Both 120- and 240-V systems are available in the computation example.

Heat Loss

The next step in the design of electric heat-tracing is the calculation of the maximum heat loss from the pipe. This is the heat loss from the pipe when the pipe is at its design temperature (maintain temperature), the ambient temperature is at its lowest, and the wind is blowing (comparable to the coldest day of the year with a maximum wind chill). Under these worst-case conditions, the heater must be capable of replacing the heat loss in order to maintain the desired temperature.

In the majority of cases, heat loss in electric tracing applications is usually estimated from tables provided by tracing manufacturers or by means of computer programs. Table B6.7 is a typical heat-loss table from a heat-tracing manufacturer. Several things should be noted about this table:

- It is based on fiberglass insulation. Correction factors for other types of insulation are given in the lower left-hand corner.
- A 10 percent safety factor has been included. This is fairly standard practice in the industry.
- The table is based on a 20-mi/h (36-km/h) wind. In the absence of wind (indoors), the heat loss will be reduced by about 10 percent. Wind speeds above 20 mi/h (36 km/h) will have very little additional effect on the total heat loss, generally less than 1 percent when one is dealing with an insulated pipe. Although the resistance of the air film can change, the total resistance—insulation plus air film—will not be altered significantly since most of that resistance is provided by the insulation.
- The amount of additional heat-tracing needed for valves is indicated in the Valve Heat-Loss Factors table in the lower right-hand corner of Table B6.7. Several additional feet of tracing will be needed for each controller in an insulated enclosure.

The heat loss per foot of pipe is calculated from Table B6.7 by following the procedure indicated in the thermal design guide chart (Fig. B6.14) as follows:

- First, move across the top to locate the 4-in-pipe column.
- Next, moving down the column, stop at the row corresponding to 1 in of insulation (left vertical axis).
- Following the calculation instruction method, a temperature differential $T_m - T_a$ of 50°F yields a heat loss of 5.4 W/ft.
- Since the actual temperature differential is 40°F or 5°C (40°F or 5°C maintain, 0°F or −18°C minimum ambient), interpolation is required, and the final result is 5.4 W/ft × 40/50 = 4.3 W/ft.

This, then, is the heat loss; including a 10 percent safety factor, of the pipe with the ambient temperature at 0°F, the pipe at 40°F (5°C), and the wind blowing 20 mi/h (32 km/h). The heater selected must be able to provide at least this much heat at a pipe temperature of 40°F (5°C).

The equation used to calculate heat loss from IEEE Standard 515–1983 is[59]:

$$q = \frac{T_m - T_a}{R_0 + R_1 + R_i + R_{co}} \tag{B6.1}$$

where q = heat loss per unit length of pipe at minimum ambient temperature, Btu/(h · ft)
T_m = pipe maintenance temperature, 40°F (5°C)
T_a = minimum ambient temperature, 0°F (−18°C)
R_0 = resistance to heat flow due to air film around outside insulation surface
R_1 = resistance of insulation to heat flow
R_i = resistance of inside air film between pipe and insulation
R_{co} = resistance to heat flow from fluid film on inner wall of pipe

Heater Cable Selection

After the data are collected, the procedure for selecting heating cables is as follows:

1. Select the heater family to be used based on the ''maintain'' and exposure temperatures. Table B6.8 shows the temperature ratings for a series of commercial heaters. Based on a maintenance temperature T_m of 40°F (5°C) and an exposure temperature T_e of 140°F (60°C), the economical choice is the heater family with lowest output capable of sustaining the required maintain temperature requirement and capable of withstanding the maximum intermittent exposure temperature.

Choice: Heater family with T_m = 150°F (66°C), T_e = 185°F (85°C) (B family).

2. Select the power output of the heater based on the heat loss and the desired maintain temperature. In the example computation, a power output of at least 4.3 W/ft at 40°F (5°C) is required. [Both the power output and the maintain temperature must be specified in order to select the correct heater. A power output of 4.3 W/ft, for example, at 140°F (60°C) instead of 40°F (5°C), would lead to the selection of an entirely different heater finally.] Figure B6.15 gives the power outputs for various families of heaters. Once again, the most economical selection is the heater with the minimum power output needed to make up the heat loss at a specified T_m of 40°F (5°C):

Choice: Heater with power output of 5.7 W/ft at 40°F (5°C). [Output specification is based on 1 ft (0.3 m) of heater per 1 ft (0.3 m) of pipe.]

In view of the heat replacement requirement, an alternate design solution could have employed a lower-cost heater with an output of only 3.5 W/ft in a spiral configuration of 1.23 ft (0.4 m) of heater per 1 ft (0.3 m) of pipe. The accepted practice of most experienced users in North America is to avoid spiraling.

Spiraling increases installation costs and time, and in many cases it also increases material costs. For example, analysis of the selection options above demonstrates that although the cost per foot of the 4.3 W/ft heater is about 10 percent greater than that of the 3.5 W/ft heater, the spiraling requirement increases the overall material cost of the latter by 23 percent. This comparison does not include the additional cost of labor required for a spiral installation. In areas with very low labor costs, the economics of spiraling can be more attractive. Spiraling is most often employed in high-heat-loss configurations where the alternative is the use of multiple strips to generate adequate heat.

In the event that a selection outcome indicates the need for more than one heater, it may be appropriate to review the heater family chosen. For example, while a heater output of 4.3 W/ft at 140°F (60°C) would require three strips of the heater selection E in Fig. B6.15, that same heat replacement could be more economically supplied by a single heater strip from selection D.

3. Select the voltage classification. The 240-V heaters have circuit lengths approximately twice as long as those of the 120-V heaters. Minimizing the number of circuits is one of the most effective ways to reduce the costs of an electric heat-tracing system.

Choice: 240-V heater.

Most 240-V heaters can be used at voltages ranging from 208 to 277 V, with some power adjustment factors (see Table B6.9).

For self-regulating heaters, it is important to obtain the power adjustment factor

TABLE B6.7 Pipe Heat-Loss Table

		Nominal pipe size (NPS)							
		¼	½	¾	1	1¼	1½	2	2½
			Tubing size (in)						
Insulation thickness (in)	ΔT (°F)		¾	1	1¼	1½	2		
0.5	50	1.9	2.5	2.9	3.5	4.1	4.6	5.5	6.5
	100	3.9	5.2	6.1	7.2	8.6	9.6	11.5	13.5
	150	6.1	8.1	9.5	11.2	13.4	14.9	17.9	21.1
	200	8.5	11.3	13.2	15.6	18.6	20.7	24.9	29.2
1.0	50	1.3	1.6	1.9	2.2	2.5	2.8	3.2	3.8
	100	2.7	3.4	3.9	4.5	5.2	5.8	6.8	7.8
	150	4.2	5.3	6.1	7.0	8.2	9.0	10.6	12.2
	200	5.8	7.4	8.4	9.7	11.3	12.4	14.6	16.9
	250	7.6	9.7	11.0	12.7	14.8	16.3	19.1	22.1
1.5	50	1.1	1.3	1.5	1.7	1.9	2.1	2.4	2.8
	100	2.2	2.8	3.1	3.5	4.0	4.4	5.1	5.8
	150	3.5	4.3	4.8	5.5	6.3	6.9	8.0	9.1
	200	4.8	5.9	6.7	7.6	8.7	9.5	11.0	12.6
	250	6.3	7.8	8.7	9.9	11.4	12.4	14.4	16.5
	300	7.9	9.7	11.0	12.4	14.3	15.6	18.1	20.6
	350	9.6	11.9	13.3	15.1	17.4	19.0	22.0	25.1
2.0	50	0.9	1.1	1.3	1.4	1.6	1.8	2.0	2.3
	100	2.0	2.4	2.7	3.0	3.4	3.7	4.2	4.8
	150	3.1	3.7	4.2	4.7	5.3	5.8	6.6	7.5
	200	4.3	5.2	5.8	6.5	7.4	8.0	9.2	10.4
	250	5.6	6.8	7.5	8.5	9.6	10.4	12.0	13.5
	300	7.0	8.5	9.4	10.6	12.1	13.1	15.0	17.0
	350	8.5	10.3	11.5	12.9	14.7	15.9	18.2	20.6
2.5	50	0.9	1.0	1.2	1.3	1.4	1.6	1.8	2.0
	100	1.8	2.2	2.4	2.7	3.0	3.3	3.7	4.2
	150	2.8	3.4	3.7	4.2	4.7	5.1	5.8	6.5
	200	3.9	4.7	5.2	5.8	6.5	7.0	8.0	9.0
	250	5.1	6.1	6.8	7.6	8.5	9.2	10.5	11.7
	300	6.4	7.7	8.5	9.5	10.7	11.5	13.1	14.7
	350	7.8	9.3	10.3	11.5	13.0	14.0	15.9	17.9
3.0	50	0.8	1.0	1.1	1.2	1.3	1.4	1.6	1.8
	100	1.7	2.0	2.2	2.4	2.7	2.9	3.3	3.7
	150	2.6	3.1	3.4	3.8	4.3	4.6	5.2	5.8
	200	3.6	4.3	4.8	5.3	5.9	6.4	7.2	8.0
	250	4.8	5.7	6.2	6.9	7.8	8.3	9.4	10.5
	300	6.0	7.1	7.8	8.7	9.7	10.4	11.8	13.2
	350	7.3	8.6	9.5	10.5	11.8	12.7	14.3	16.0
4.0	50	0.7	0.9	0.9	1.0	1.1	1.2	1.4	1.5
	100	1.5	1.8	2.0	2.1	2.4	2.5	2.9	3.2
	150	2.4	2.8	3.0	3.4	3.7	4.0	4.4	4.9
	200	3.3	3.9	4.2	4.6	5.2	5.5	6.2	6.8
	250	4.3	5.1	5.5	6.1	6.7	7.2	8.1	8.9
	300	5.4	6.3	6.9	7.6	8.5	9.0	10.1	11.2
	350	6.6	7.7	8.4	9.3	10.3	11.0	12.3	13.6

Insulation factors

Preformed pipe insulation	Insulation factor (f)	Based on K factor @ 50°F mean temp (Btu/h · °F · ft^2/in)
Glass fiber (ASTM C547)	1.00	.25
Calcium silicate (ASTM C533)	1.50	.375
Cellular glass (ASTM C552)	1.60	.40
Rigid cellular urethane (ASTM C591)	0.66	.165
Foamed elastomer (ASTM C534)	1.16	.29
Mineral fiber blanket (ASTM C553)	1.20	.30
Expanded perlite (ASTM C610)	1.50	.375

TABLE B6.7 Pipe Heat-Loss Table (*Continued*)

Nominal pipe size (NPS)											
3	3½	4	6	8	10	12	14	16	18	20	24
7.7	8.6	9.6	13.6	17.4	21.4	25.2	27.5	31.3	35.0	38.8	46.2
16.0	18.0	20.0	28.4	36.3	44.6	52.5	57.4	65.2	73.0	80.8	96.3
25.0	28.1	31.2	44.3	56.6	69.6	81.9	89.5	101.7	113.8	126.0	150.2
34.6	39.0	43.3	61.5	78.6	96.6	113.6	124.2	141.1	158.0	174.8	208.5
4.4	4.9	5.4	7.5	9.4	11.5	13.5	14.7	16.6	18.6	20.5	24.4
9.1	10.2	11.2	15.6	19.7	24.0	28.1	30.6	34.7	38.7	42.8	50.9
14.2	15.9	17.5	24.3	30.7	37.4	43.8	47.8	54.1	60.4	66.7	79.4
19.7	22.0	24.2	33.7	42.5	51.9	60.7	66.2	75.0	83.8	92.5	110.0
25.8	28.7	31.7	44.0	55.6	67.9	79.4	86.6	98.1	109.6	121.0	143.9
3.2	3.6	3.9	5.3	6.7	8.1	9.4	10.2	11.5	12.9	14.2	16.8
6.7	7.4	8.1	11.1	13.9	16.8	19.6	21.3	24.0	26.8	29.5	35.0
10.5	11.6	12.7	17.3	21.6	26.2	30.5	33.2	37.5	41.8	46.1	54.6
14.5	16.1	17.6	24.0	30.0	36.3	42.3	46.0	52.0	57.9	63.8	75.7
19.0	21.0	23.0	31.4	39.2	47.5	55.3	60.2	68.0	75.7	83.5	99.0
23.8	26.3	28.8	39.3	49.2	59.6	69.3	75.4	85.1	94.9	104.6	124.0
28.9	32.0	35.0	47.8	59.8	72.4	84.3	91.7	103.5	115.4	127.2	150.8
2.6	2.9	3.1	4.2	5.2	6.3	7.3	7.9	8.9	9.9	10.9	12.9
5.5	6.0	6.6	8.8	10.9	13.1	15.2	16.5	18.6	20.7	22.8	26.9
8.5	9.4	10.2	13.8	17.0	20.5	23.8	25.8	29.0	32.3	35.5	42.0
11.8	13.0	14.2	19.1	23.6	28.4	32.9	35.7	40.2	44.7	49.2	58.2
15.5	17.0	18.5	24.9	30.9	37.2	43.1	46.7	52.6	58.5	64.3	76.1
19.4	21.3	23.2	31.2	38.7	46.6	54.0	58.6	65.9	73.3	80.6	95.3
23.6	25.9	28.3	38.0	47.1	56.6	65.6	71.2	80.2	89.1	98.1	115.9
2.3	2.5	2.7	3.6	4.4	5.2	6.1	6.6	7.4	8.2	9.0	10.6
4.7	5.2	5.6	7.4	9.1	10.9	12.6	13.7	15.3	17.0	18.7	22.0
7.4	8.1	8.7	11.6	14.2	17.0	19.7	21.3	23.9	26.5	29.1	34.3
10.2	11.2	12.1	16.1	19.7	23.6	27.2	29.5	33.1	36.7	40.3	47.5
13.3	14.6	15.8	21.0	25.8	30.9	35.6	38.6	43.3	48.0	52.8	62.2
16.7	18.3	19.8	26.3	32.3	38.7	44.6	48.4	54.3	60.2	66.1	77.9
20.3	22.2	24.1	32.0	39.3	47.1	54.3	58.8	66.0	73.2	80.4	94.7
2.0	2.2	2.4	3.1	3.8	4.5	5.2	5.6	6.3	7.0	7.6	9.0
4.2	4.6	4.9	6.5	7.9	9.4	10.8	11.7	13.1	14.5	15.9	18.7
6.6	7.1	7.7	10.1	12.4	14.7	16.9	18.3	20.5	22.6	24.8	29.2
9.1	9.9	10.7	14.0	17.1	20.4	23.4	25.3	28.3	31.4	34.4	40.4
11.9	12.9	14.0	18.3	22.4	26.6	30.6	33.1	37.1	41.0	45.0	52.8
14.9	16.2	17.5	23.0	28.1	33.4	38.4	41.5	46.5	51.4	56.3	66.2
18.1	19.7	21.3	28.0	34.1	40.6	46.7	50.5	56.5	62.5	68.5	80.5
1.7	1.8	2.0	2.5	3.1	3.6	4.1	4.4	5.0	5.5	6.0	7.0
3.5	3.8	4.1	5.3	6.4	7.5	8.6	9.3	10.3	11.4	12.4	14.5
5.5	6.0	6.4	8.3	10.0	11.8	13.4	14.5	16.1	17.8	19.4	22.7
7.6	8.3	8.9	11.4	13.8	16.3	18.6	20.0	22.3	24.6	26.9	31.4
10.0	10.8	11.6	15.0	18.1	21.3	24.3	26.2	29.2	32.2	35.2	41.1
12.5	13.5	14.6	18.8	22.6	26.7	30.5	32.8	36.6	40.3	44.1	51.5
15.2	16.5	17.7	22.8	27.5	32.4	37.1	39.9	44.5	49.0	53.6	62.6

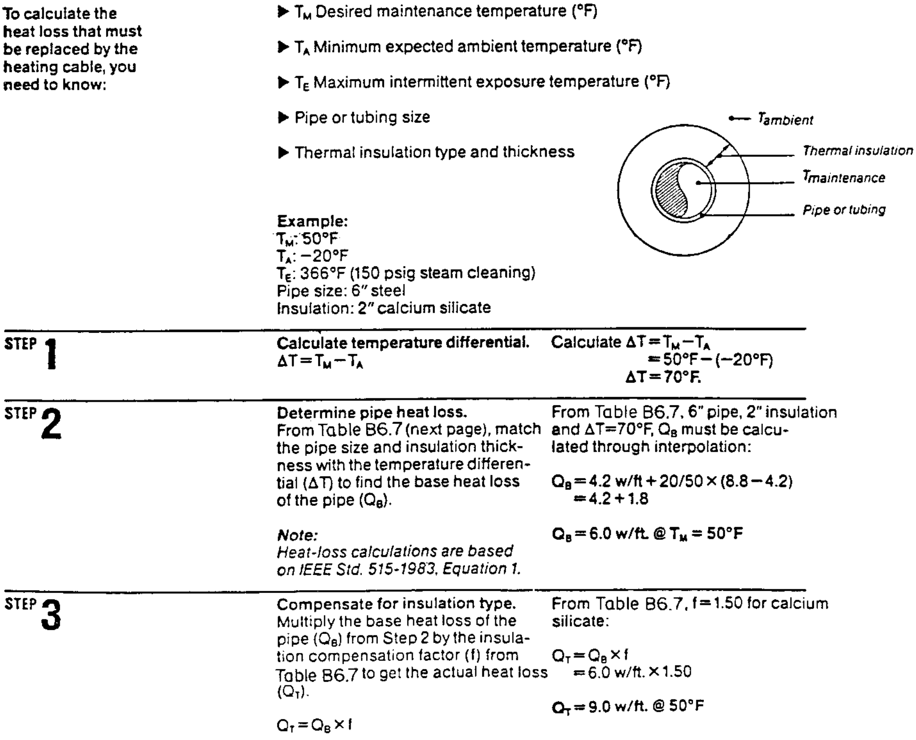
Valve heat-loss factors

Valve type	Heat-loss factor
Gate	4.3
Butterfly	2.3
Ball	2.6
Globe	3.9

Example:
Heat loss for a 2-in gate valve is 4.3 times the heat loss for 1 ft of pipe of the same size and insulation.

Pipe heat loss (Q_B) is shown in watts per foot. Heat-loss calculations are based on IEEE Std. 515—1983, Equation 1, with the following provisions: pipes insulated with glass fiber in accordance with ASTM C547; pipes located outdoors in a 20-mph wind; no insulating air-space assumed between pipe and insulation; no insulating air-space assumed between the insulation and outer cladding. A 10% safety factor has been included.

Source: Chemelex Auto-Trace Design Guide, *Raychem Corp., Chemelex Division, Menlo Park, CA., 1988, pp. 8–9.*



To calculate the heat loss that must be replaced by the heating cable, you need to know:

- ▶ T_M Desired maintenance temperature (°F)
- ▶ T_A Minimum expected ambient temperature (°F)
- ▶ T_E Maximum intermittent exposure temperature (°F)
- ▶ Pipe or tubing size
- ▶ Thermal insulation type and thickness

Example:
T_M: 50°F
T_A: −20°F
T_E: 366°F (150 psig steam cleaning)
Pipe size: 6″ steel
Insulation: 2″ calcium silicate

STEP 1

Calculate temperature differential.
$\Delta T = T_M - T_A$

Calculate $\Delta T = T_M - T_A$
$= 50°F - (-20°F)$
$\Delta T = 70°F$.

STEP 2

Determine pipe heat loss.
From Table B6.7 (next page), match the pipe size and insulation thickness with the temperature differential (ΔT) to find the base heat loss of the pipe (Q_B).

Note:
Heat-loss calculations are based on IEEE Std. 515-1983, Equation 1.

From Table B6.7, 6″ pipe, 2″ insulation and ΔT=70°F, Q_B must be calculated through interpolation:

$Q_B = 4.2$ w/ft + 20/50 × (8.8 − 4.2)
$= 4.2 + 1.8$

$Q_B = 6.0$ w/ft. @ $T_M = 50°F$

STEP 3

Compensate for insulation type.
Multiply the base heat loss of the pipe (Q_B) from Step 2 by the insulation compensation factor (f) from Table B6.7 to get the actual heat loss (Q_T).

$Q_T = Q_B \times f$

From Table B6.7, f = 1.50 for calcium silicate:

$Q_T = Q_B \times f$
$= 6.0$ w/ft. × 1.50

$Q_T = 9.0$ w/ft. @ 50°F

FIGURE B6.14 Thermal design chart. (Chemelex Auto-Trace Design Guide, *Raychem Corp., Chemelex Division, Menlo Park, CA., 1988, p. 7.*)

TABLE B6.8 Heater Cable Temperature Ratings

Family	Maximum maintenance temperature T_m	Maximum intermittent exposure T_e
B	150°F (65°C)	185°F (85°C)
Q	225°F (110°C)	225°F (110°C)
X	250°F (121°C)	420°F (215°C)

Select the heating-cable family. Considering the maximum intermittent exposure temperature T_e and the desired maintenance temperature T_m, select the appropriate heating cable family.

Source: Raychem Design Guide for Insulated Pipes and Tubing, *H5149, Raychem Corp., Menlo Park, CA.*

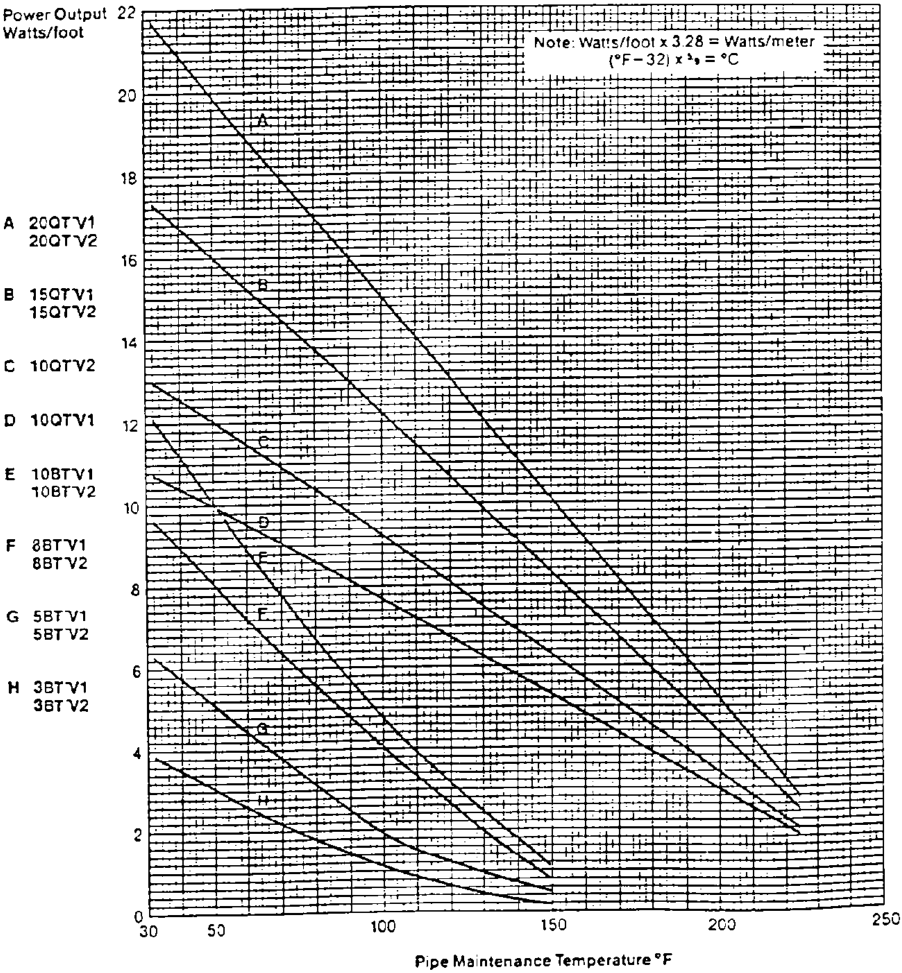


FIGURE B6.15 Thermal output of selected heaters. (Auto-Trace Design Guide, *Raychem Corp., Menlo Park, CA, 1991, p. 12.*)

from the manufacturer instead of calculating the factor by using the square of the voltage. Ohm's law ($P = V^2/R$) still applies; however, for self-regulating heaters, the electric resistance R does not remain constant. The result is an adjustment factor smaller than the change calculated from the square of the voltage.

4. Select the heater cable construction. The choice in cable construction is between a base heater with one insulating jacket and no braid or ground path, and a heater equipped with a braid and extra outer jacket. (A braid is required in all areas, both hazardous, i.e., classified area, and ordinary.)

Choice: Heater with a tinned braided, tinned copper (braid supplies the required ground path), and a fluoropolymer outer jacket for chemical resistance.

TABLE B6.9 Voltage Adjustment Chart

	240-V Autotrace heating cables powered at alternate voltages					
	208 V			277 V		
Heating cable	Power output, %	Circuit length adjustment factor	Maximum circuit length	Power output, %	Circuit length adjustment factor	Maximum circuit length
3BTV2-CT	82	0.99	630 ft (192 m)	113	1.03	710 ft (216 m)
5BTV2-CT	85	0.99	500 ft (152 m)	112	1.07	585 ft (178 m)
8BTV2-CT	89	0.93	385 ft (117 m)	108	1.08	465 ft (142 m)
10BTV2-CT	89	0.93	330 ft (100 m)	108	1.05	395 ft (120 m)
10QTV2-CT	85	0.98	365 ft (111 m)	118	1.03	410 ft (125 m)
15QTV2-CT	91	0.94	360 ft (110 m)	109	1.06	370 ft (113 m)
20QTV2-CT	90	0.92	350 ft (107 m)	107	1.06	430 ft (131 m)
5XTV2-CT	84	0.94	720 ft (220 m)	119	0.97	750 ft (229 m)
10XTV2-CT	83	0.95	510 ft (155 m)	119	0.97	575 ft (175 m)
15XTV2-CT	85	0.92	415 ft (126 m)	119	0.97	475 ft (145 m)
20XTV2-CT	88	0.92	350 ft (107 m)	119	0.97	440 ft (134 m)

Source: Auto-Trace Design Guide, *Raychem Corp., Menlo Park, CA.*

The heater cable selection is now complete. Tables B6.10, B6.11, and B6.12 are the outputs of the computer selection program run with the data used in the calculated example. As expected, the program arrived at the same heater selection as the manual technique employed in the above discussion. The program output also provides important information that augments the design selection function.

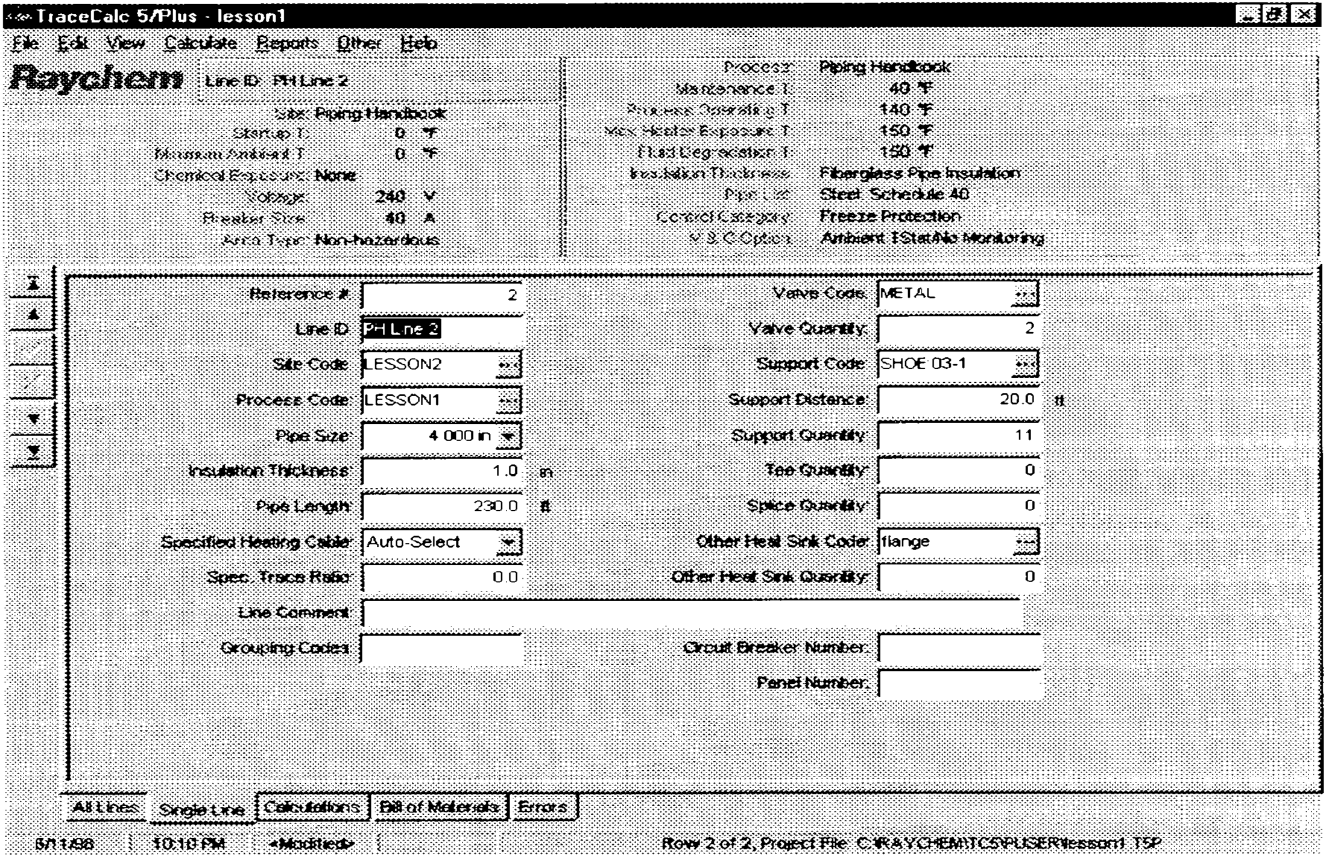
The design summary given in Table B6.10 provides the start-up load in amperes per foot as well as the operating load. The Min *T* maintained and Max *T* maintained are the maximum and minimum temperatures, respectively, the pipe can reach in this application in the absence of thermostatic control.

The Min *T* maintained 48°F (9°C) will be the pipe temperature on the coldest day [0°F (−18°C)] with the wind blowing and minimum heater output. The Max *T* maintained will be the pipe temperature on the warmest day [95°F (35°C)] with no wind and maximum heater output. These temperature values are useful in determining whether thermostats are needed. (See the later section ''Control and Monitoring.'')

The computer heat-tracing program can be used to implement a design change. The actual application for the computation example is a waterline in a process area where many of the process lines are regularly cleaned by purging with 150 psig (1035 kPa) steam at 366°F (186°C). It was concluded by the design team that a reasonable possibility existed that the traced line might be inadvertently steam-cleaned. What would the consequences be?

The new variable requires that the maximum heater exposure temperature be changed from 140°F (60°C) to 390°F (199°C), and the resulting output is given in Tables B6.13, B6.14, and B6.15. The most significant outcome of the requirement for a higher maximum temperature of exposure is the program's substitution of a heater designed to withstand the temperatures encountered during steam cleaning. The results of the new calculation show that the Min *T* maintained is relatively

TABLE B6.10 Design Input Summary for Computational Example Input. (Metric Unit Support Available in Other Unit of Measure Menu)



Line ID: PH Line 2

Site: Piping Handbook
Startup T: 0 °F
Minimum Ambient T: 0 °F
Chemical Exposure: None
Voltage: 240 V
Breaker Size: 40 A
Area Type: Non-hazardous

Process: Piping Handbook
Maintenance T: 40 °F
Process Operating T: 140 °F
Max Heater Exposure T: 150 °F
Heat Degradation T: 150 °F
Insulation Thickness: Fiberglass Pipe Insulation
Pipe Type: Steel Schedule 40
Control Category: Freeze Protection
M & C Option: Ambient TStat/No Monitoring

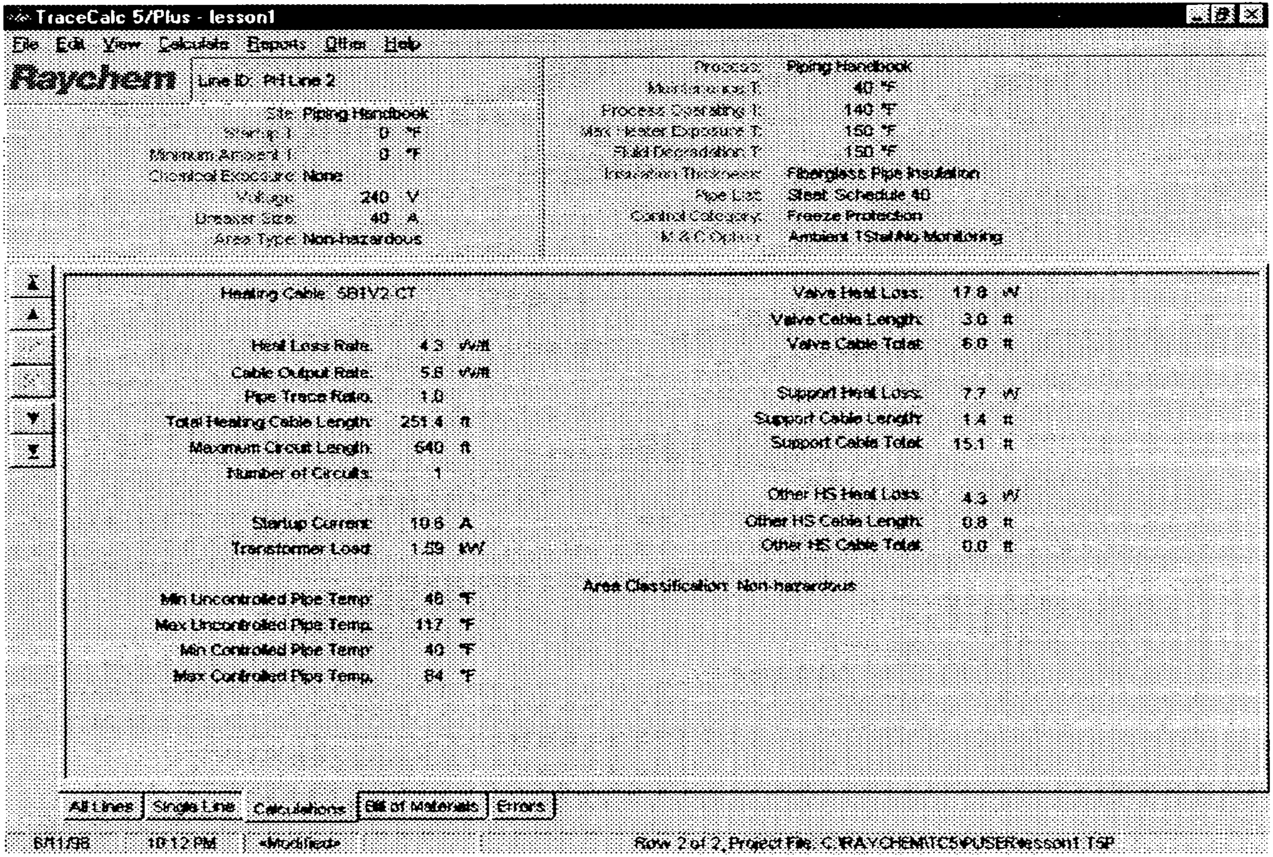
Reference #: 2
Line ID: PH Line 2
Site Code: LESSON2
Process Code: LESSON1
Pipe Size: 4.000 in
Insulation Thickness: 1.0 in
Pipe Length: 230.0 ft
Specified Heating Cable: Auto-Select
Spec. Trace Ratio: 0.0
Line Comment:
Grouping Codes:

Valve Code: METAL
Valve Quantity: 2
Support Code: SHOE 03-1
Support Distance: 20.0 ft
Support Quantity: 11
Tee Quantity: 0
Splice Quantity: 0
Other Heat Sink Code: flange
Other Heat Sink Quantity: 0
Circuit Breaker Number:
Panel Number:

5/11/98 10:10 PM <Modified> Row 2 of 2, Project File: C:\RAYCHEM\TC5PLUSER\lesson1.T5P

Source: *TraceCalc 5 Plus, Raychem Corp., Menlo Park, CA, ©1998.*

TABLE B6.11 Calculated Output from Computational Example. (Metric Unit Support Available in Other Unit of Measure Menu)



Line ID: PH Line 2

Site: Piping Handbook
Start-up T: 0 °F
Minimum Ambient T: 0 °F
Chemical Exposure: None
Voltage: 240 V
Breaker Size: 40 A
Area Type: Non-hazardous

Process: Piping Handbook
Maintain T: 40 °F
Process Operating T: 140 °F
Max Heater Exposure T: 150 °F
Fluid Degradation T: 150 °F
Insulation Thickness: Fiberglass Pipe Insulation
Pipe List: Steel Schedule 40
Control Category: Freeze Protection
M & C Option: Ambient TStat/No Monitoring

Heating Cable: 5BTV2-CT

Heat Loss Rate: 4.3 W/ft
Cable Output Rate: 5.8 W/ft
Pipe Trace Ratio: 1.0
Total Heating Cable Length: 251.4 ft
Maximum Circuit Length: 640 ft
Number of Circuits: 1

Startup Current: 10.6 A
Transformer Load: 1.59 kW

Min Uncontrolled Pipe Temp: 46 °F
Max Uncontrolled Pipe Temp: 117 °F
Min Controlled Pipe Temp: 40 °F
Max Controlled Pipe Temp: 84 °F

Valve Heat Loss: 17.8 W
Valve Cable Length: 3.0 ft
Valve Cable Total: 6.0 ft

Support Heat Loss: 7.7 W
Support Cable Length: 1.4 ft
Support Cable Total: 15.1 ft

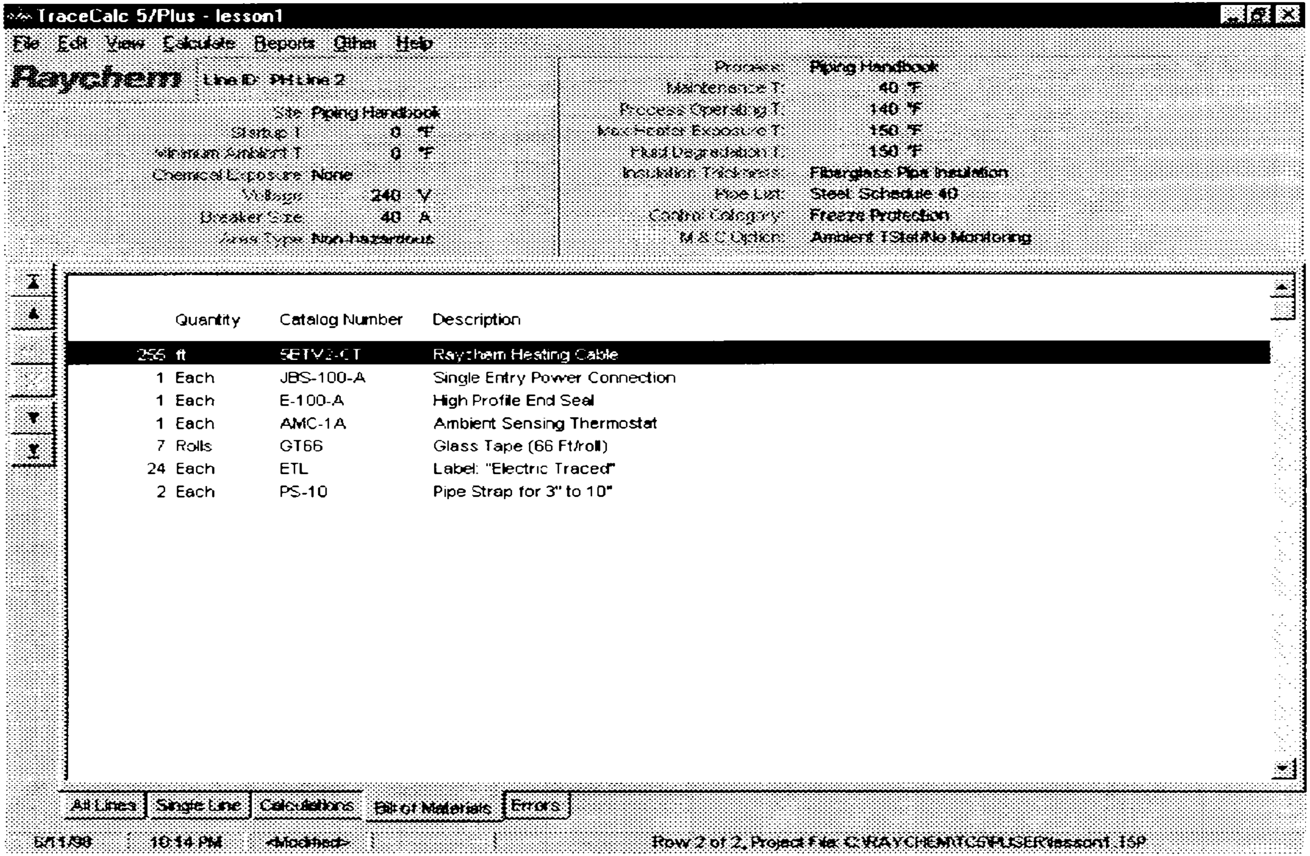
Other HS Heat Loss: 4.3 W
Other HS Cable Length: 0.8 ft
Other HS Cable Total: 0.0 ft

Area Classification: Non-hazardous

6/11/98 10:12 PM <Modified> Row 2 of 2, Project File: C:\RAYCHEM\TC5\USER\lesson1.TSP

Source: *TraceCalc 5 Plus, Raychem Corp., Menlo Park, CA, ©1998.*

TABLE B6.12 Bill of Materials for Computational Example. (Metric Unit Support Available in Other Unit of Measure Menu)



Line ID: PH Line 2

Site: Piping Handbook
Startup T: 0 °F
Minimum Ambient T: 0 °F
Chemical Exposure: None
Voltage: 240 V
Breaker Size: 40 A
Area Type: Non-hazardous

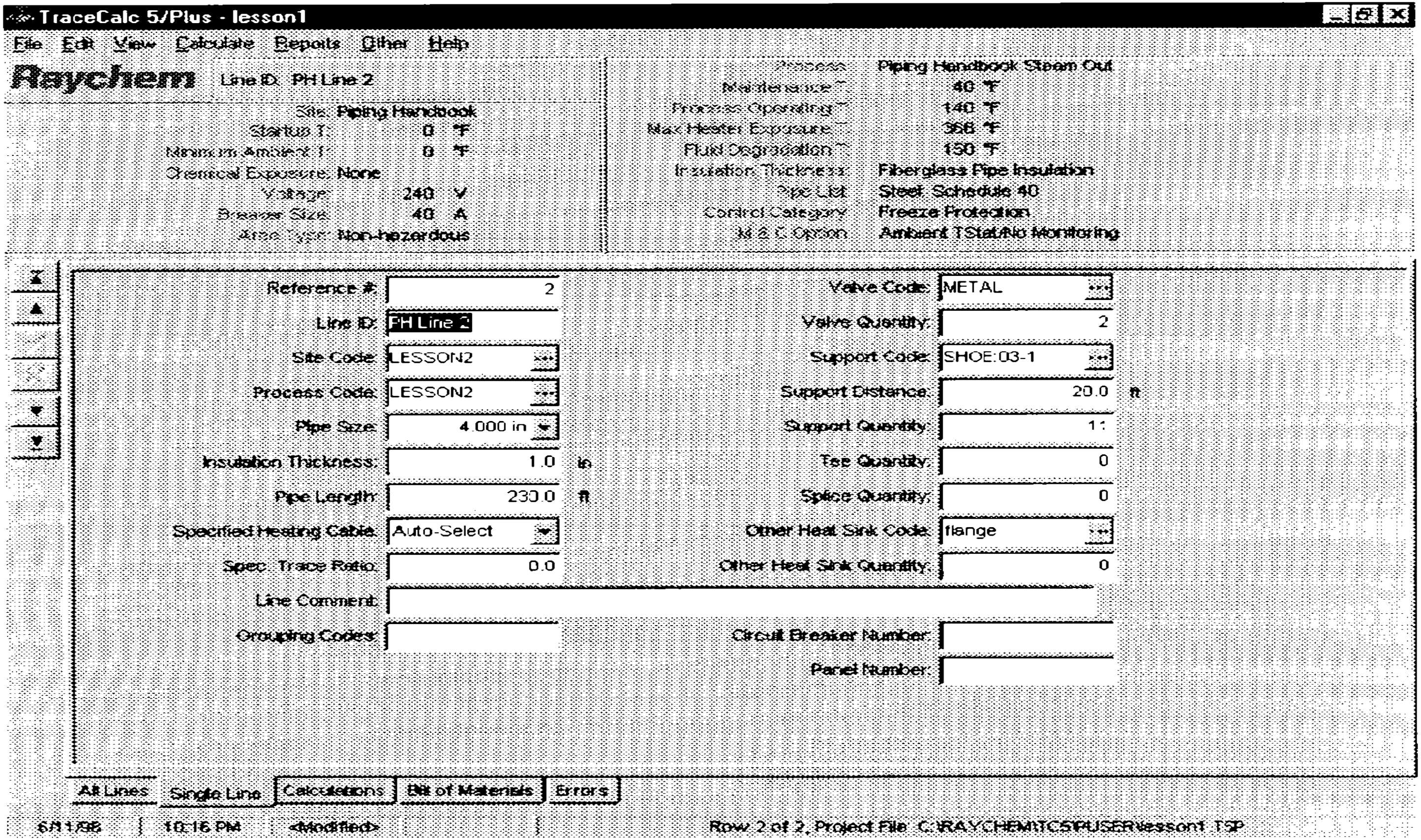
Process: Piping Handbook
Maintenance T: 40 °F
Process Operating T: 140 °F
Max Heater Exposure T: 150 °F
Fluid Degradation T: 150 °F
Insulation Thickness: Fiberglass Pipe Insulation
Pipe List: Steel Schedule 40
Control Category: Freeze Protection
M & C Option: Ambient TStat/No Monitoring

Quantity		Catalog Number	Description
256	ft	5BTV2-CT	Raychem Heating Cable
1	Each	JBS-100-A	Single Entry Power Connection
1	Each	E-100-A	High Profile End Seal
1	Each	AMC-1A	Ambient Sensing Thermostat
7	Rolls	GT66	Glass Tape (66 Ft/roll)
24	Each	ETL	Label: "Electric Traced"
2	Each	PS-10	Pipe Strap for 3" to 10"

5/11/98 10:14 PM <Modified> Row 2 of 2, Project File: C:\RAYCHEM\TC5PLUSER\lesson1.TSP

Source: *TraceCalc 5 Plus, Raychem Corp., Menlo Park, CA, ©1998.*

TABLE B6.13 Design Input Summary for Steam-Cleaned Computational Example. (Metric Unit Support Available in Other Unit of Measure Menu)



Line ID: PH Line 2

Site: Piping Handbook
Startup T: 0 °F
Minimum Ambient T: 0 °F
Chemical Exposure: None
Voltage: 240 V
Breaker Size: 40 A
Area Type: Non-hazardous

Process: Piping Handbook Steam Out
Maintenance T: 40 °F
Process Operating T: 140 °F
Max Heater Exposure T: 368 °F
Fluid Degradation T: 150 °F
Insulation Thickness: Fiberglass Pipe Insulation
Pipe List: Steel, Schedule 40
Control Category: Freeze Protection
M & C Option: Ambient TStat/No Monitoring

Reference #: 2
Line ID: PH Line 2
Site Code: LESSON2
Process Code: LESSON2
Pipe Size: 4.000 in
Insulation Thickness: 1.0 in
Pipe Length: 230.0 ft
Specified Heating Cable: Auto-Select
Spec. Trace Ratio: 0.0
Line Comment:
Grouping Codes:

Valve Code: METAL
Valve Quantity: 2
Support Code: SHOE:03-1
Support Distance: 20.0 ft
Support Quantity: 11
Tee Quantity: 0
Splice Quantity: 0
Other Heat Sink Code: flange
Other Heat Sink Quantity: 0
Circuit Breaker Number:
Panel Number:

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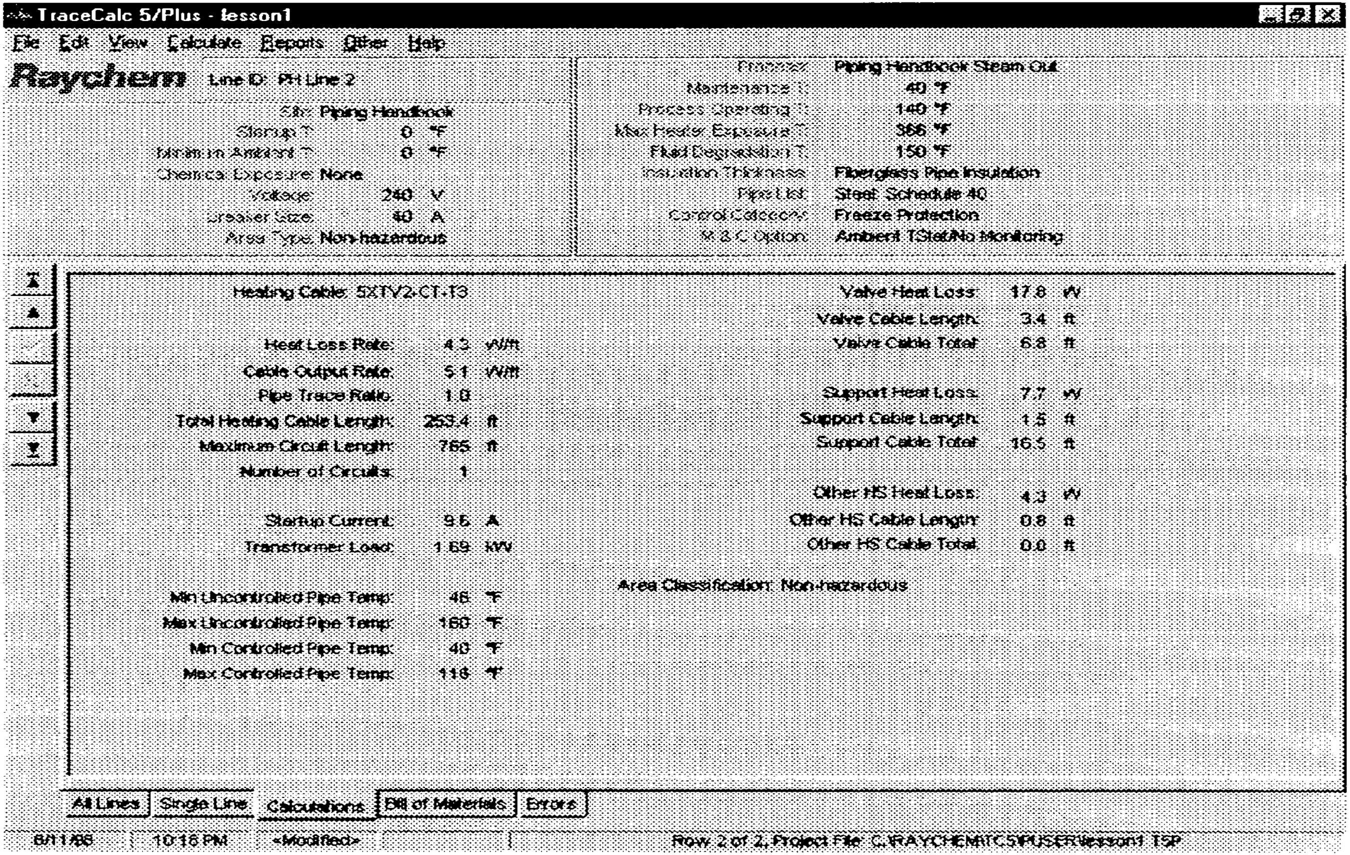
Source: *TraceCalc 5 Plus, Raychem Corp., Menlo Park, CA, ©1998.*

TABLE B6.14 Calculated Output from Steam-Cleaned Computational Example. (Metric Unit Support Available in Other Unit of Measure Menu)



Line ID: PH Line 2

Site: Piping Handbook
Startup T: 0 °F
Minimum Ambient T: 0 °F
Chemical Exposure: None
Voltage: 240 V
Breaker Size: 40 A
Area Type: Non-hazardous

Process: Piping Handbook Steam Out
Maintenance T: 40 °F
Process Operating T: 140 °F
Max Heater Exposure T: 366 °F
Fluid Degradation T: 150 °F
Insulation Thickness: Fiberglass Pipe Insulation
Pipe List: Steel Schedule 40
Control Category: Freeze Protection
M & C Option: Ambient TStat/No Monitoring

Heating Cable: 5XTV2-CT-T3

Heat Loss Rate: 4.3 W/ft
Cable Output Rate: 5.1 W/ft
Pipe Trace Ratio: 1.0
Total Heating Cable Length: 253.4 ft
Maximum Circuit Length: 765 ft
Number of Circuits: 1

Startup Current: 9.6 A
Transformer Load: 1.69 kW

Min Uncontrolled Pipe Temp: 46 °F
Max Uncontrolled Pipe Temp: 160 °F
Min Controlled Pipe Temp: 40 °F
Max Controlled Pipe Temp: 118 °F

Valve Heat Loss: 17.8 W
Valve Cable Length: 3.4 ft
Valve Cable Total: 6.8 ft

Support Heat Loss: 7.7 W
Support Cable Length: 1.5 ft
Support Cable Total: 16.5 ft

Other HS Heat Loss: 4.3 W
Other HS Cable Length: 0.8 ft
Other HS Cable Total: 0.0 ft

Area Classification: Non-hazardous

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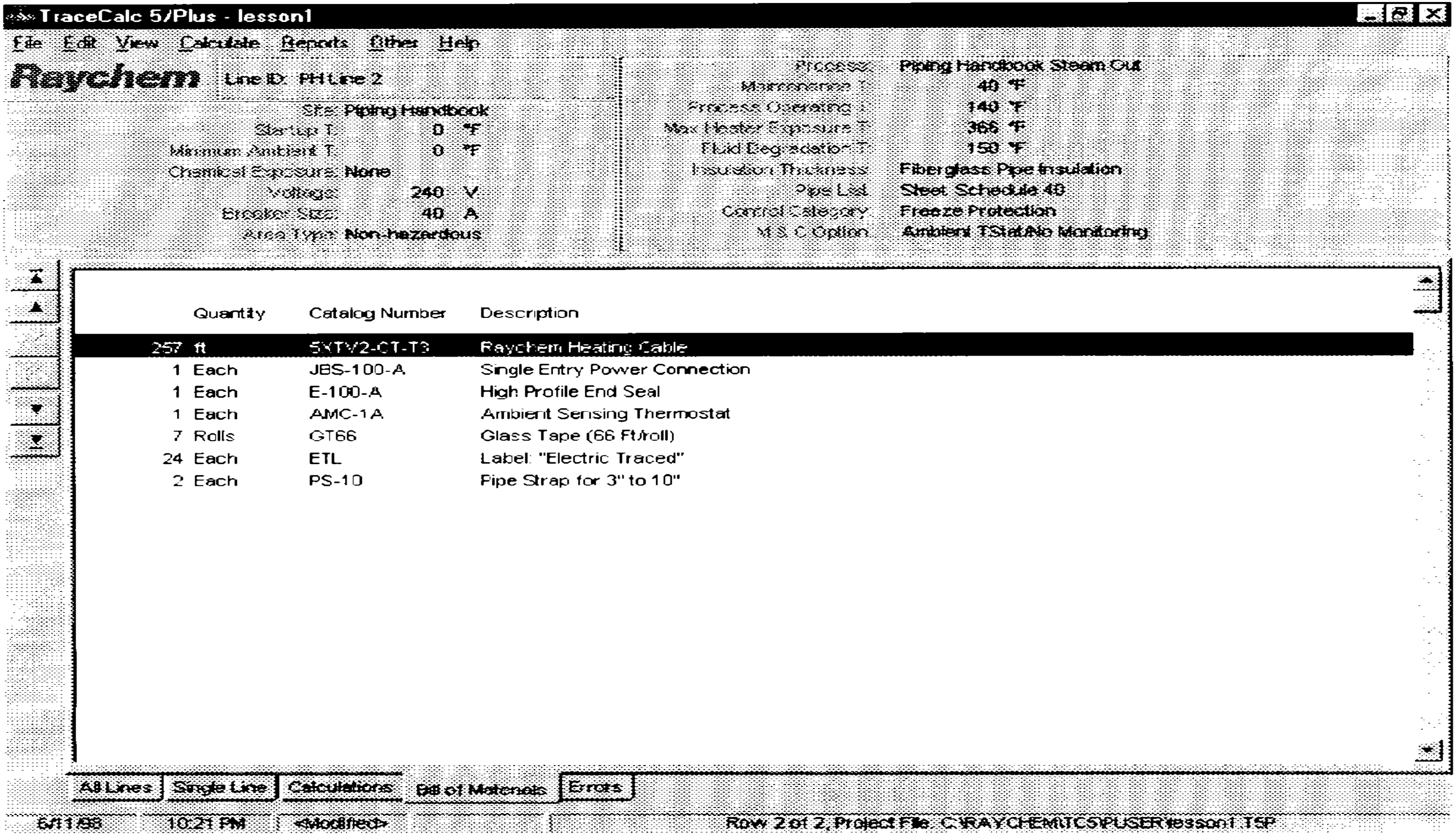
Source: *TraceCalc 5 Plus, Raychem Corp., Menlo Park, CA, ©1998.*

TABLE B6.15 Bill of Materials for Steam-Cleaned Computational Example. (Metric Unit Support Available in Other Unit of Measure Menu)



Line ID: PH Line 2

Site: Piping Handbook
Startup T: 0 °F
Minimum Ambient T: 0 °F
Chemical Exposure: None
Voltage: 240 V
Breaker Size: 40 A
Area Type: Non-hazardous

Process: Piping Handbook Steam Out
Maintenance T: 40 °F
Process Operating T: 140 °F
Max Heater Exposure T: 366 °F
Fluid Degradation T: 150 °F
Insulation Thickness: Fiberglass Pipe Insulation
Pipe Lst: Steel Schedule 40
Control Category: Freeze Protection
M.S.C Option: Ambient TStat/No Monitoring

	Quantity	Catalog Number	Description
257	ft	5XTV2-CT-T3	Raychem Heating Cable
1	Each	JBS-100-A	Single Entry Power Connection
1	Each	E-100-A	High Profile End Seal
1	Each	AMC-1A	Ambient Sensing Thermostat
7	Rolls	GT66	Glass Tape (66 Ft/roll)
24	Each	ETL	Label: "Electric Traced"
2	Each	PS-10	Pipe Strap for 3" to 10"

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Source: *TraceCalc 5 Plus, Raychem Corp., Menlo Park, CA, ©1998.*

unchanged at 47°F (8°C), but the Max T maintained has increased to 146°F (63°C). This increase in the maximum temperature is a function of the original heater's power temperature curve, which is considerably steeper when compared with the type selected for the new set of conditions. If a constant-wattage heater had been selected, the maximum temperature would be well above 146°F (63°C). The design change calculation illustrates two important rules to follow when using self-regulating heaters:

Rule 1. Never risk exposing the heater to temperatures in excess of those for which the heater is rated. If the heater originally specified (T_e = 185°F, or 85°C) had been installed and the pipe were subsequently steam-cleaned, the heater would have suffered an irreversible resistance increase; i.e., it would no longer be functional. The cost of repair/removal of the lagging, removal and possible replacement of the insulation, replacement of the heater, followed by reinstallation of the entire system, would be more than the original price of the system. And this sum is in addition to process-related costs which might result from heater failure, such as the replacement of frozen and/or broken pipe, or in lengthy production downtime when a failed tracer shuts down a process.

Because of the potential costs resulting from tracer failure caused by inadvertent exposure to steam, experienced heat-tracing professionals generally use heaters capable of withstanding steam cleaning in any area where steam cleaning is practiced.

Rule 2. Select the heater with the lowest temperature rating capable of withstanding the anticipated maximum exposure temperature.

1. The higher-temperature heaters are generally more expensive because they are made from more costly heat-resistant polymers.
2. The higher temperature generated by high-temperature heaters can cause safety problems. Unnecessary heating also increases the rate of corrosion and wastes energy. Higher-temperature heaters often require a more expensive heater control system.

While the potential savings in purchasing a low-temperature heater are not worth the risk of heater failure from steam cleaning, these additional costs are not justified in applications where there is no risk of steam exposure. Water pipe in a pollution control area where no steam is available is an example.

Component and Accessory Selection

The components necessary to provide power and to terminate, splice, and tee the heat-tracing are provided by the manufacturer. With self-regulating and zone, it is important to acquire components designed for the heat-tracing system selected, to ensure that the approvals are valid. Each supplier's system of components is unique and generally not interchangeable with that of other manufacturers. In some cases the components from one supplier may work in another's heat-tracing system, but they must be verified to be acceptable for such use. The components available in this example are shown in Fig. B6.16.

Each manufacturer provides or recommends a complete system of components and accessories to install the heater as part of a total tracing system. Table B6.12 (the design exhibit from the computer solution) shows a complete bill of material for the design example. In addition to the power connection and the end termination, a splice and/or a tee may be required. The other materials on the list are

- ETL (electric traced label). The National Electric Code requires that electric

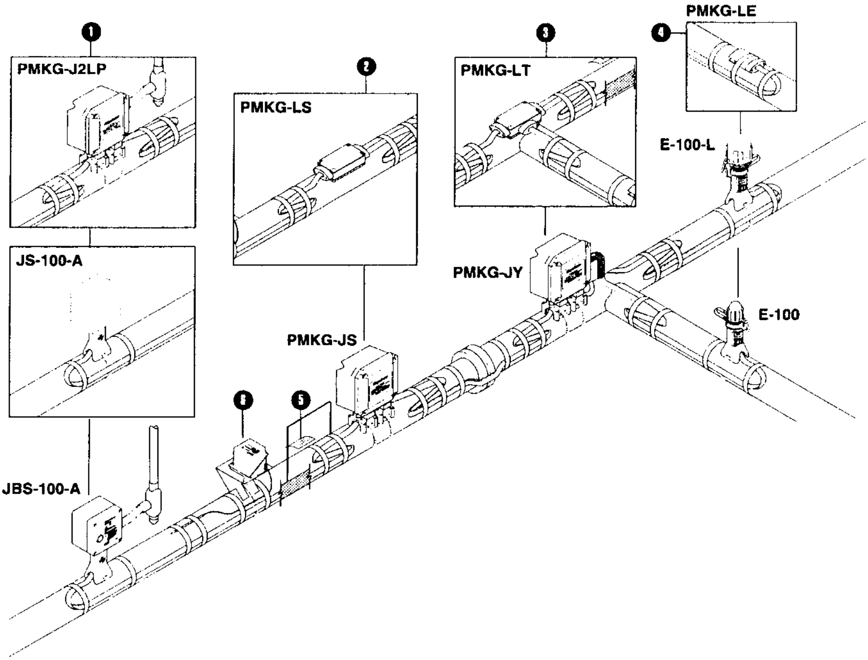

FIGURE B6.16 Component selection guide. (Raychem Design Guide, *Raychem Corp., Menlo Park, CA, © 1998.*)

traced pipes have signs on the outside of the lagging on alternating sides every 10 ft.

- GT66 glass tape for taping the heater to the pipe.
- PS-10 pipe straps to attach the power connection assembly to the pipe.

Control and Monitoring

Control and monitoring must be considered as part of the system design since these elements can have a significant effect on the circuit layout.

1. Control. Control is the ability to interrupt and restore power to the heat tracer in order to maintain the temperature within a preset range and/or to save energy. Monitoring is any method that provides an ongoing indication of the heating system's operational status. The major control options are as follows:

No Control, or Self-Regulating Control. The heater is constantly supplied with full power, and the self-regulating characteristics of the heater control the pipe temperature. In a limited number of tracing situations, a no-control configuration can also be used with constant-wattage heaters. If a circuit without controller is used in a hazardous area, the T rating must be calculated at 120 percent of the rated voltage. (See the earlier section "Area Classification.")

Self-regulating control offers the lowest installed cost and the highest reliability.

This system uses more energy because the heater is always on. Approximately 8 to 12 percent of the freeze protection systems and 10 to 15 percent of the process temperature systems use self-regulating control.

Ambient-Sensing Control. A thermostat measures the ambient temperature. The heating system is energized when the ambient temperature drops below a preset level. Ambient sensing offers a degree of control for very little incremental cost (one thermostat and the required switching device). Of the freeze protection systems, particularly those that use self-regulating heaters, 70 to 80 percent use ambient-sensing control.

Line-Sensing Control. A sensor measures the temperature of the pipe. Each heater circuit is individually controlled to maintain the design temperature by either varying or turning the circuit voltage on and off (see Fig. B6.17). Line sensing is often used for process control systems. It offers the highest degree of temperature control and the lowest energy use, but it also has the highest installed costs.[60]

Dead Leg Control. A thermostat measures a section of traced pipe that cannot have fluid flow (a "dead leg"). The entire system is turned on when the temperature drops below the design temperature to be maintained. Dead leg sensing requires

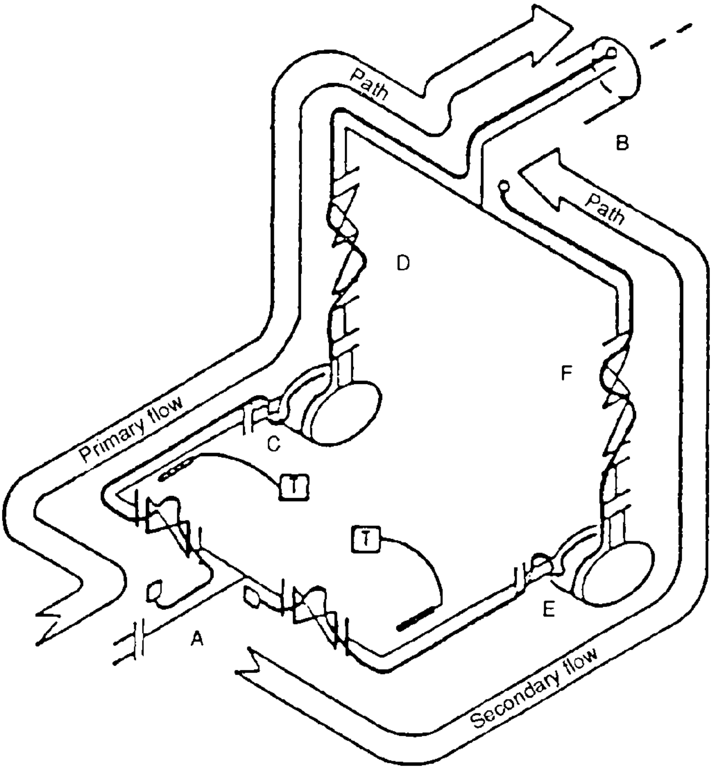

FIGURE B6.17 Line-sensing circuit design for multiple flow paths. (*M. Sarfatti, editor.* Raychem Engineering Manual for Electric Heat Tracing Systems, *vol. 1, U.S. edition, pp. 2–27, Fig. 3-11.*)

only one thermostat and eliminates the need for the additional circuits required with line-sensing control. The downside of dead leg sensing is the inability of the system to reduce heat output even when flow conditions within the pipe would dictate such an adjustment. (By definition, the dead leg on which the sensor is placed is in a permanent no-flow condition.[61]) Presently, about 5 to 10 percent of the systems installed use dead leg control.

Proportional Ambient-Sensing Control (PASC). A new addition to available control methods is proportional ambient-sensing control. This control will measure ambient, determine the heat-up and cool-down rates of the smallest pipe, and cycle the power to the heater circuit depending on these variables. This will impose a duty cycle on the heating system that decreases the variability of the temperature range. One can think of it as global control. If they are self-regulating heaters, they will provide a local override for much tighter temperature control. At minimum ambient temperature, the power is on 100 percent of the time. As the ambient temperature approaches the maintain temperature, the duty cycle decreases proportionally. If the maintain temperature is above the maximum ambient temperature, the controller never shuts off completely, and there will always be some proportion of the duty cycle maintained. With self-regulating heaters, this system also adjusts heat input for valves and supports, depending on their actual thermal characteristics instead of the design characteristics. If a valve is a little hot, the self-regulating heater supplies a little less heat; if the valve is a little cold, the heater supplies a little more heat.

This global system reduces circuit costs since now flow paths are not a critical part of the design. This method has been used with freeze protection systems with ambient control, and now this improved PASC version is available for process temperature maintenance systems. Significant cost savings and a tighter temperature control band are available. Figure B6.18 shows the relationship between control type and temperature variation for various electric heat-tracing control categories for a typical freeze protection application. The minimum ambient temperature is 0°F (−18°C) and the maintain temperature is 40°F (5°C). A new expert system design program (Ref. 54) is able to calculate various expected results when the design parameters are specified in the program. These programs will predict the

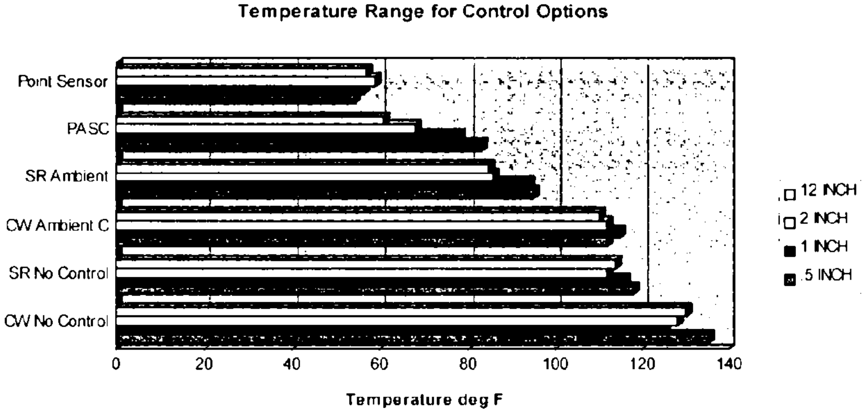

FIGURE B6.18 Temperature range for control options.

steady-state temperatures for various piping systems including the valves and supports.

Stabilized design temperatures for Zone 1 and Zone 2 are also calculated. The combination of PASC with self-regulating heaters gives the electric heat-trace designer an optimum system to develop cost-effective and reliable systems that provide significantly less temperature variation across the different thermal features of a typical piping system.

2. Monitoring. *Monitoring* is the term used to describe any mechanism that provides information about the functional state of the heat-tracing system.[62] Most heat-tracing systems employ one of the following monitoring methods:

No Monitoring. The vast majority of heat-tracing systems are not provided with monitoring. Users have found that properly installed heat-tracing systems are very reliable, and under these circumstances, the high cost of monitoring is not generally warranted.

Ground-Fault Monitoring. Leakage current from the heater strip can be monitored with a ground-fault circuit breaker. An annunciator is included to indicate when the breaker has tripped, or alternatively, a relay is switched in response to a loss of voltage. This method is also a good way to monitor the heater strip for mechanical abuse since significant mechanical damage to a braided heater will result in leakage current to the braid. Use of ground-fault breakers with annunciators or relays provides the highest value of added protection per monitoring dollar invested.

Voltage Monitoring. Voltage at the beginning of the circuit can be sensed by actuating a relay-driven alarm whenever there is no voltage from the circuit breaker. A signal light is the simplest technique for monitoring voltage at the end of the circuit. This system is often used for freeze protection applications with ambient-sensing control and either self-regulating heaters or zone heaters but not with MI cable, as MI cable usually requires line-sensing thermostats.

Although a light indicator is a low-cost system, it requires a visual inspection to detect voltage loss. Thus, there is a good chance that a cut line will lead to a failure before it is detected. The technique does not work well with line-sensing thermostats or dead leg control since there is no way to distinguish if the light is off because of a cut line or because of a cycling thermostat.

Voltage Sensing with Microprocessor-Based Monitoring and Control System. The best of these systems uses resistance temperature detectors (RTDs). (See Fig. B6.19.) Since the bus wires of the heaters are used to carry the detector signal, any cut in the line trips the alarm due to signal loss. Microprocessor-based monitoring and control systems are capable of providing very accurate information

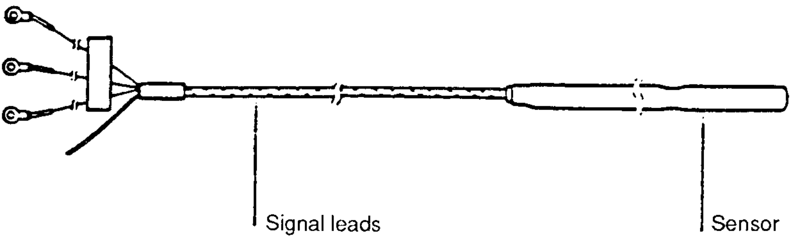

FIGURE B6.19 Resistance temperature device. (Chemelex Auto-Trace Installation and Operation Manual, *Raychem Corp., Process Division, Menlo Park, CA, p. 1.5.3.*)

about the condition of the heat-tracing system and the pipe temperature, but they often cost as much as the heat-tracing system itself. For this reason, they are generally used only for temperature-critical applications.

Temperature Sensing. Thermostats can be used to alarm when the temperature at any monitored point drops below the alarm temperature. This is a good technique when there is only one or two points (such as critical control valves) where the proper temperature must be maintained.

The current draw of the heat tracer can also be monitored with microprocessor-based systems using a simple ammeter to indicate the current draw of each circuit. Current monitoring works well with all types of heaters when line-sensing control is used, but is a poor choice in applications employing ambient-sensing control and self-regulating heaters.

Power Line Carrier

A distributed data acquisition system that uses the ac power lines as the data transmission medium is a new addition to the monitoring and control area. The system uses frequency shift keying to encode digital data onto the power line network. Digital 0s and 1s are transmitted by changing the frequency of the carrier (e.g., from 50 to 47.5 kHz). The digital data are transmitted in a message package that includes an error check to guarantee data integrity.

The system uses power from a parallel-circuit heat-tracing cable, measures the temperature at the end of the pipe, and transmits these data to a monitoring panel. If a signal is received, the user knows there is voltage to the end of the circuit. In addition, the temperature of the pipe is known. Alarm limits and automatic enunciation to a central location can be set. Significant savings are realized when both field power and instrument wiring are eliminated.

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