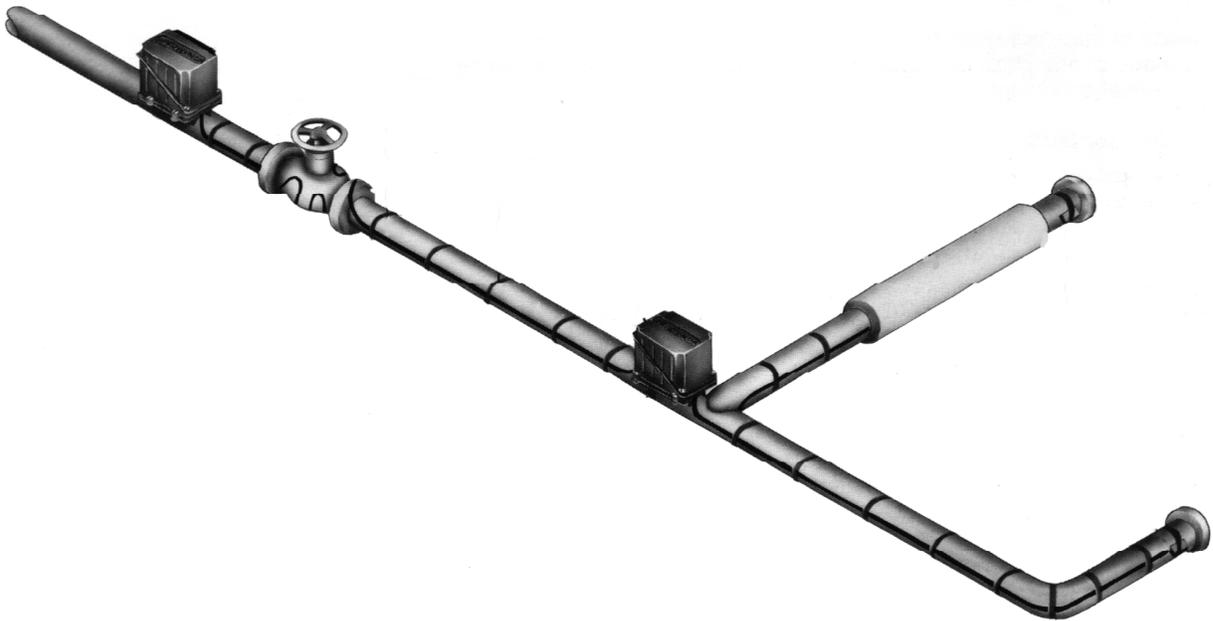


# HEAT TRACING PRODUCTS

## Training Manual



CHROMALOX<sup>®</sup> TRAINING

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The facts and the recommendations made in this publication are based on our own research and the research of others and are believed to be accurate.

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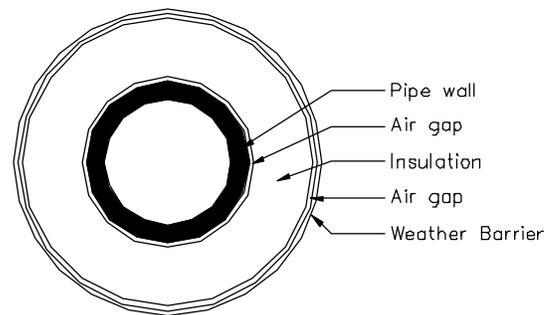
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## Chapter 1: Heating Fundamentals

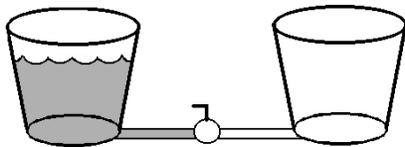
Before plunging headfirst into a myriad of heat trace designs, products and applications, one must first have an understanding of the basics of heat loss and why heat trace products are used. This section deals with the basic principles of heat transfer and the calculations used for pipes and vessels. It has been left as a review of general thermal concepts and is not intended to be a detailed discussion of thermodynamics.

Illustration 1 depicts a sectional view of a typical pipe system. It consists of the pipe, insulation, a weather barrier and gaps between each layer. If the pipe and its contents are warmer than the surrounding environment, heat will be transferred from the pipe to the air. If enough heat is transferred out of the pipe, the pipe contents may thicken or solidify resulting in damage to pipes or pumping equipment. The following sections address fundamental heat transfer concepts used to arrive at a general formula that is used in heat loss calculations.



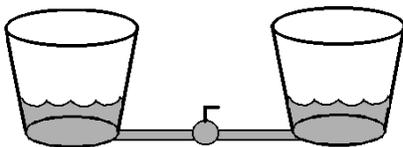
**Illustration 1**

Consider Illustrations 2 and 3. Two water buckets are joined by a pipe. In Illustration 2, the valve is closed and the right bucket is empty. When the valve is opened, water flows through the valve and into the right bucket as shown in Illustration 3. The two buckets will attain an equal amount of water in each.



**Illustration 2**

Heat flows from one object to another in much the same way as water. Objects of unequal temperatures in a thermal system tend toward thermal equilibrium. The hotter object transfers some of its heat to the colder object until the objects are the same temperature.



**Illustration 3**

Heat can be transferred by way of conduction, convection and radiation. Of the three methods of transferring heat, conduction is considered to be the most efficient method.



**Convection.** Losses by convection can be seen to be negligible in a system without extensive calculations. In example 1.1, we disregarded convection losses by assuming no air gaps between any surface. In actuality, small air gaps exist between the surface wall and insulation. The air gaps are normally slight, less than 1/10<sup>th</sup> of an inch, and prevent the flow of air which restricts convection. Although small air gaps do not affect heat loss via convection, their thermal resistive properties should be analyzed to determine the contribution to system heat loss through conduction. Using Equation 1.1, consider the following.

Assume Illustration 1 consists of 1" fiberglass insulation and the air gap between the pipe wall and insulation is 0.05 inch. Using Equation 1.1, we can calculate the resistance of the insulation and air gap. A ratio of the two resistances indicates that insulation has the greatest impact in overall thermal resistance and minor imperfections in applying insulation are minimal.

$$R = L/k$$

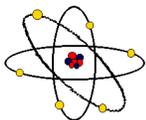
$$R_{\text{(fiberglass)}} = \frac{(1)}{(0.25)} = 4.00$$

$$R_{\text{(air gap)}} = \frac{(0.05)}{(0.167)} = 0.299$$

$$\begin{aligned} R_{\text{(total)}} &= R_{\text{(fiberglass)}} + R_{\text{(air gap)}} \\ &= 4.00 + 0.299 \\ &= 4.299 \end{aligned}$$

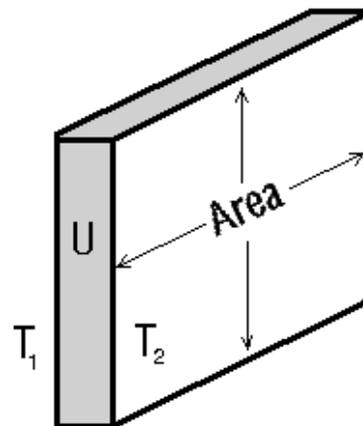
$$\begin{aligned} \text{Percentage of resistance due to air gap} &= 0.299/4.299 \\ &= 6.95\% \end{aligned}$$

**Radiation** Radiant heat loss occurs as a result of highly energized molecules transmitting heat by way of waves or particles. For significant heat loss to occur from radiation, the hotter surface must be well above ambient temperature - much higher than what is observed in typical heat trace applications. Therefore, heat loss from radiation can be ignored.



In practical, low to medium temperature applications, convection and radiation account for about 10% of the overall heat loss of a system. By adding 10%, the general formula for calculating the heat loss of a system via conduction, convection and radiation can be calculated.

**Flat Surface Heat Loss Calculations.** The terminology *heat loss* commonly refers to the heat transfer of an object to its ambient environment. This implies that the object in question, a wall in Illustration 6 for example, is at a temperature above the ambient temperature. Mathematically, the formula for calculating the heat loss of a system through conduction, expressed in BTU/hour is:



**Illustration 6**

Eq. 1.2  $Q = (U)(A)(\Delta T)$ , where:

U = conductance, BTU/(ft<sup>2</sup>)(°F)(hr)  
A = surface area of object, ft<sup>2</sup>  
 $\Delta T$  = Temperature difference °F, T<sub>1</sub>-T<sub>2</sub>

Conductance is the inverse of resistance, R, and can be expressed as  $U = 1/R$  or  $U = k/L$ . Rewriting Equation 1.2, the basic heat loss Q can be written as:

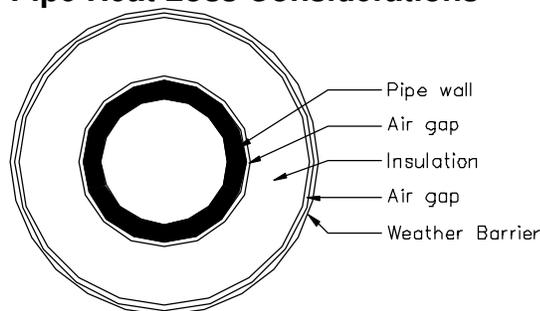
Eq 1.3  $Q = \frac{(k)(A)(\Delta T)(1.1)}{L}$  Heat Loss, BTU/hr

**BTUs and Watts, A Comparison.** Equation 1.3 calculates the heat loss of an entire flat area in BTU/hr. Electricity is normally sold by kilowatt hours. Therefore, Equation 1.3 needs a conversion factor to convert from BTU to watts. One watt equals 3.412 BTUs. Modifying Equation 1.3 yields a new formula:

Eq. 1.4  $Q = \frac{(k)(A)(\Delta T)(1.1)}{(3.412)(L)}$

Heat Loss, Watts/hr

**Pipe Heat Loss Considerations**



Equation 1.4 is based on the heat loss of an *entire* flat area where the inside area of the insulation wall is the same as the outside area. To simplify heat loss calculations pipe heat loss is based on the heat loss per linear foot rather than the entire area of any given length. Also, for pipe insulation, the outer area of insulation is greater than the inner area due to wrapping insulation around the cylindrical

shape of a pipe. As a result, consideration must be made for this difference when calculating heat loss for pipes.

Since pipe heat loss is based on watts per linear foot rather than the entire pipe area, the mean insulation area for one linear foot of pipe is calculated as shown in Illustration 7. The mean area  $A$  is the natural logarithm ratio of the outer and inner insulation diameters. To calculate pipe heat loss, Equation 1.4 is rewritten as:

$$\text{Eq. 1.5} \quad Q = \frac{2 \pi (k)(\Delta T)}{(40.944)\ln(D_o/D_i)} \quad \text{Heat Loss, Watts/ft hr}$$

where  $2 \pi$  is part of the formula for calculating the area of a cylinder  
 40.944 is 12 inches of pipe multiplied by the 3.412 conversion factor  
 $D_o$  is the outer insulation diameter  
 $D_i$  is the inner insulation diameter  
 $\ln(D_o/D_i)$  is the mean circumference of insulation

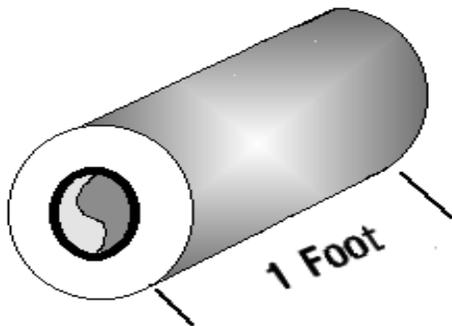


Illustration 7

Equation 1.5 is the heat loss for pipes due to conduction only. By adding 10% for convective and radiant losses, the final form of the basic heat loss formula is:

$$\text{Eq. 1.6} \quad Q = \frac{2 \pi (k)(\Delta T)(1.1)}{(40.944)\ln(D_o/D_i)} \quad \text{W/Ft*hr}$$

## Primary vs. Supplemental Heating

Primary heating is the process of adding heat to raise the temperature of a system whereas supplemental heating is intended to only maintain the heat of a system at its current level. Typically, a higher density of heat must be added for primary heat as opposed to supplemental heating. As an analogous example, consider the amount of gasoline required to accelerate from 0 MPH to 60 MPH and maintain speed at 60MPH. The amount of fuel and energy required to accelerate is much greater than the amount of fuel needed to simply maintain speed. This section will illustrate this concept by example.

**Primary Heat.** Primary heating is used to raise the temperature of a material or materials. The basic formula for calculating the amount of heat required for primary heating in watts/hour is:

$$\text{Eq. 1.7} \quad Q = \frac{mc\Delta T}{3.412} \text{ W/hr} \quad \text{where } m = \text{the mass (weight) of the material(s)}$$

$$c = \text{the specific heat of the material(s)}$$

$$\Delta T = \text{the required temperature increase}$$

$$3.412 = \text{conversion from BTU to watts}$$

This formula can be used provided that no material is changing state, i.e. changing from solid to liquid or liquid to gas. In the event that materials are changing state, additional heat must be added to accommodate for the latent heat of fusion and/or vaporization. When multiple materials are to be heated, the formula can be expanded as follows.

$$Q = \frac{[(m_1c_1) + (m_2c_2) + \dots + (m_nc_n)] \Delta T}{3.412} \quad \text{where } n = \text{the number of materials}$$

Each material's weight and specific heat are multiplied then added together. The result is then multiplied by the temperature increase and finally converted to watts per hour.

The amount of primary heat required is proportional to the time required to achieve the final temperature. If one hour heat up requires 10 watts, then a two hour heat up requires 5 watts per hour for two hours. Conversely, a half hour heat up requires 20 watts to heat the system.

Example 1.2

*Raise a 4" steel pipe filled with water from 40°F to 90°F in one hour, base the calculation on one foot of pipe. From various tables found in engineering handbooks, the following information is gathered.*

Weight of one foot of 4" pipe = 10.79 lb  
 Weight of water in one foot of pipe = 5.50 lb  
 Specific heat of steel = 0.12  
 Specific heat of water = 1.00

$$Q = \frac{[(10.79)(0.12) + (5.50)(1.00)] 50}{3.412}$$

$$= 99.6 \text{ watts per hour}$$

If two hours were acceptable, the amount of primary heat to be supplied per linear foot on the pipe is 49.8 watts for two hours.

**Supplemental Heat.** Supplemental heat is a more formal term for the heat loss calculations derived in Equations 1.4 and 1.6. Supplemental heat is the amount of heat required to maintain the existing heat level.

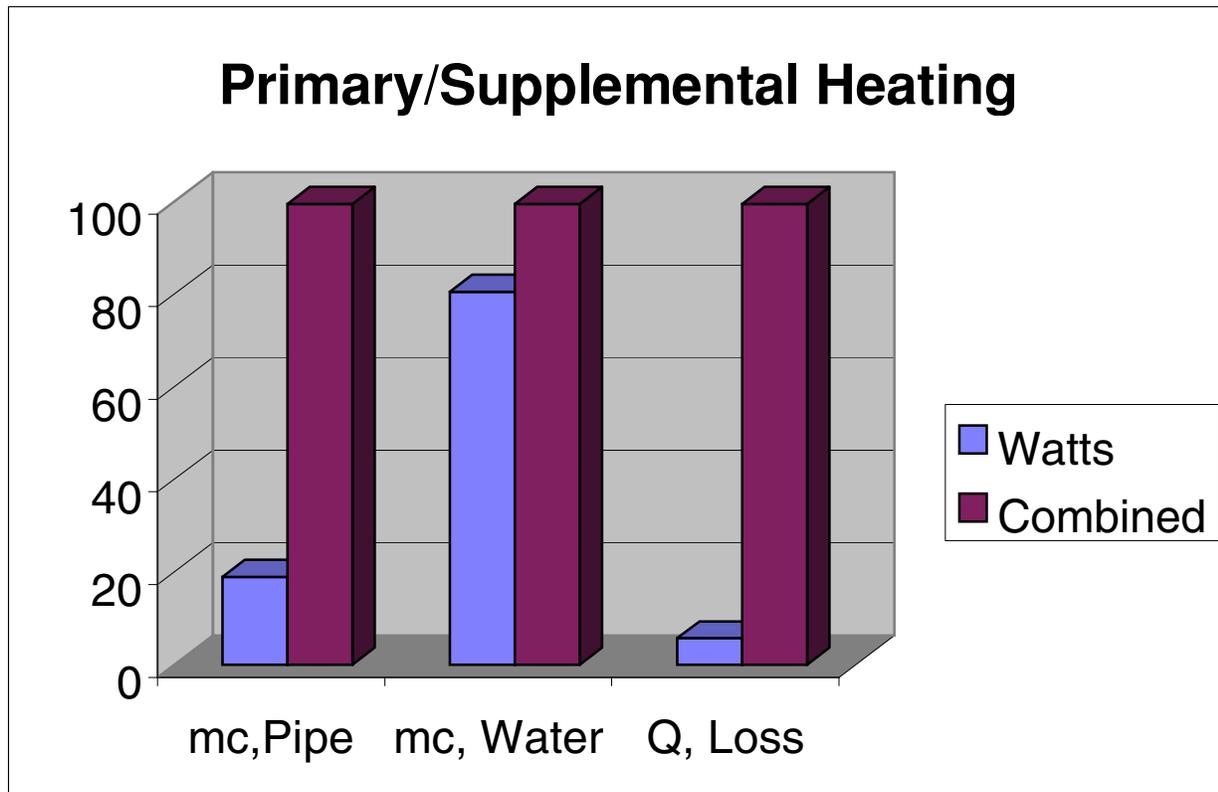
Example 1.3

Building on example 1.2, calculate the amount of heat loss, or supplemental heat required to maintain the pipe and water at 90°F in a 40°F ambient using 1" of fiberglass insulation. The k-factor for fiberglass is 0.25 BTUin/hrft<sup>2</sup>°F. A 4" pipe has an outside diameter of 4.5 inches.

$$\begin{aligned} \text{From Equation 1.6} \quad Q &= \frac{2 \pi (k) (\Delta T) (1.1)}{(40.944) \ln(D_o/D_i)} \\ Q &= \frac{2 \pi (0.25)(50)(1.1)}{40.944 \ln(6.5/4.5)} \\ &= 5.74 \text{ watts per hour} \end{aligned}$$

Comparing primary to supplemental heat for this example, it is apparent that applying supplemental heat is much more economical since it uses 17.4 times less heat to maintain the final temperature than to raise the temperature. Graph 1 details the comparison of required heat.

**Graph 1: Primary vs Supplemental Heating**





**Table 1 Insulation K-Factors\***

Temperature, °F	0	50	100	150	200	250	300	350	400
Fiberglass	.23	.25	.27	.29	.32	.34	.37	.39	.41
Calcium Silicate	.35	.37	.40	.43	.45	.47	.50	.53	.55
Urethane	.18	.17	.18	.22	.25	---	---	---	---
Cellular Glass	.38	.40	.46	.50	.55	.58	.61	.65	.70

\*Data based on average values from various insulation manufacturers.

Given the difference in heat loss between examples 1.4 and 1.5, one obvious conclusion is to always use insulation with the lowest k-factor to minimize the heat loss of the system. Designing for the lowest heat loss may not always obtain the best results. For example, polyurethane is a better insulator than fiberglass but has an upper service temperature limit of only 200°F. Cellular glass does not insulate as well as fiberglass but will not absorb liquids in the event of leaks. In most cases though, the decision of which insulation to use is best left to an architectural firm or plant specification.

On rare occasions multiple layers of different insulation materials are used. When this occurs, the overall thermal resistance of the system is calculated. Each material's resistance is calculated separately then summed into the overall system resistance. This example is beyond the scope of this discussion and should be reviewed using a thermodynamics text for a more thorough understanding.

### Summary

- Heat loss through conduction accounts for about 90% of overall heat loss in a typical pipe and equipment application. A 10% safety factor is added to account for convection and radiant losses.
- Equation 1.4 is the general formula for calculating heat loss on flat surfaces.
- Equation 1.6 is the general formula for calculating heat loss on pipes.
- Primary heat is used to raise the overall temperature of a system; supplemental heat is used to just maintain the existing temperature level in a system.
- Primary heat requires a significantly higher watt density than offsetting heat losses.
- Insulation k-factors are a measure of its ability to retard heat transfer.

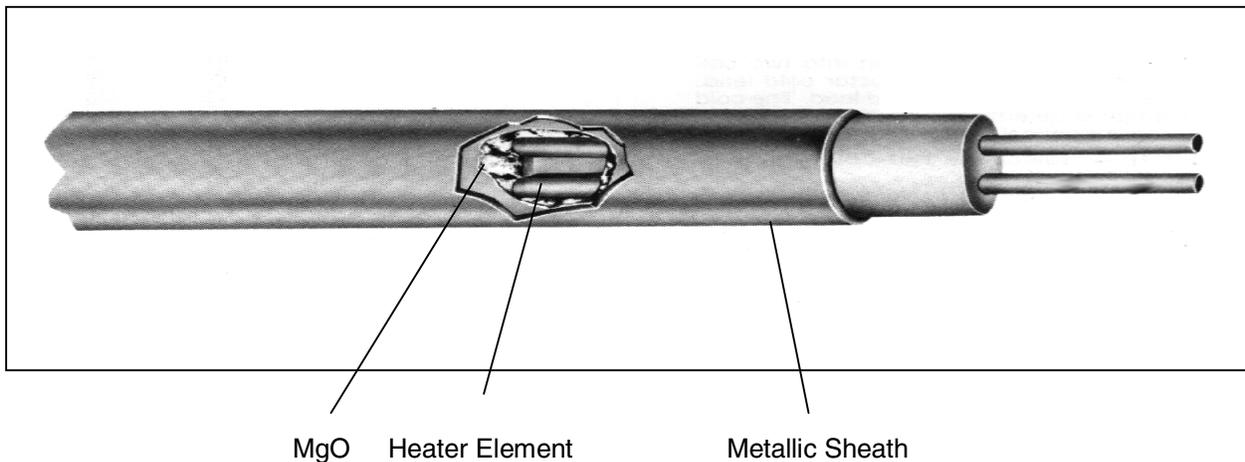
### Problems:

- 1• Calculate the heat loss of a 6" steel pipe at 320°F in a 70°F ambient insulated with 2" fiberglass insulation. A 6" pipe has an outer diameter of 6.625 inches. What is the temperature of the outer wall of the pipe if the inside wall is 320°F? Assume an air gap of 0.07 inch between the pipe and insulation.
- 2• Calculate the heat required in one hour to raise one foot of an empty 4" pipe from 0°F to 50°F if the pipe is covered with 1 inch of fiberglass insulation. Air weighs 0.08 lb/ft<sup>3</sup> and has a specific heat of 0.2377. The pipe weighs 10.79 lbs, has an internal volume of 0.088 cubic feet, has an outer diameter of 4.5 inches, and has a specific heat of 0.12.
- 3• If the pipe in problem 2 is at 50°F then filled with 50°F water, how long will it take for the water to drop to 32°F if the pipe is in a 32°F ambient and no supplemental heat is applied? The water has a weight of 5.5 lbs per linear foot of pipe.

## Chapter 2: Heating Cable Products

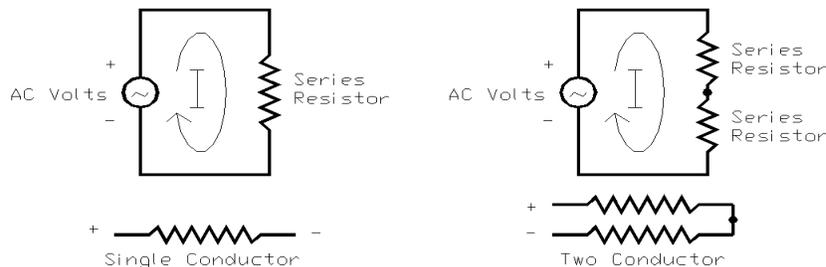
With the basics of heat loss in place, it's time to review the products that are used to replace heat loss. This chapter will focus on the various constructions, operating characteristics and features/benefits of heating cable products available today. These products will be used in Chapter 3 - Designs.

**In the beginning – Mineral Insulated Cable.** The first heating cables were similar to tubular heating elements, and being dielectrically insulated with magnesium oxide (MgO), were named mineral insulated (MI) cables. MI cables consist of a single or multiple metallic heating elements surrounded by compacted MgO. The heating element is a series resistor that travels the length of the heating cable. Applying voltage to the element produces heat. The rugged outer protective jacket is typically constructed of copper, stainless steel or corrosion resistant alloys and acts as a ground path. MI cables are known for their solid, impact resistant construction that enables long cable life in harsh, high temperature environments.



**Illustration 9 – Mineral Insulated Construction**

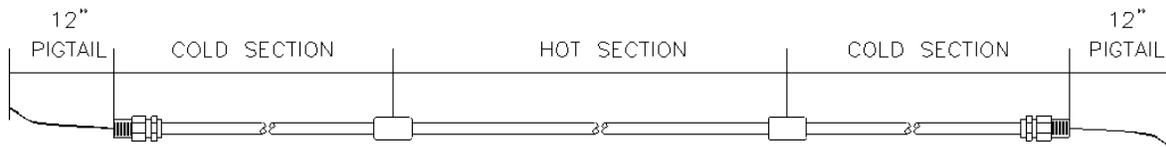
Utilizing series resistance element design, mineral insulated cables offer flexibility in output wattage ranges. By changing the length, voltage or resistance value of the element, a variety of watt densities is available. Illustration 10 depicts the electrical characteristics of MI cables for both single and two conductor designs.



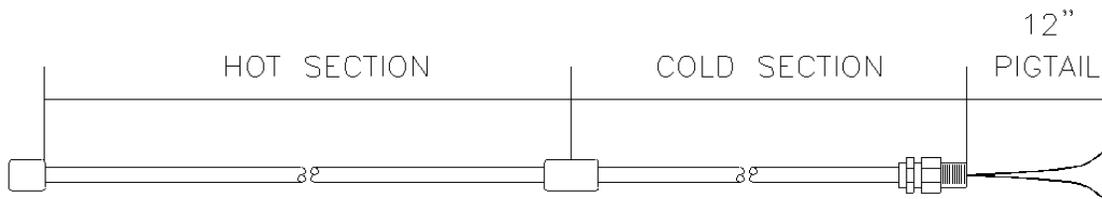
**Illustration 10 – Single and Two Conductor MI Cables Electrical Operation**

To assemble an MI cable, the exact length and construction style must be known since it affects whether the unit can be manufactured. Because of welding and testing procedures involved in MI cable assembly, MI cables are always factory assembled. Consequently, all construction information must be known in advance of manufacturing. Field modifications are extremely difficult because changes in length or voltage affect the overall cable output wattage.

There are practical limits to the number of heater resistance values that an MI cable manufacturer will produce. Therefore, MI cable designs are subject to availability of resistance values. Also, manufacturers have specific assembly styles that are used to construct MI cable. The two most popular designs are shown in Illustrations 11 and 12. Each consists of pigtail leads to supply voltage, cold lead wire, a hot-to-cold joint and the heater section. Check product data sheets for resistance tables.



**Illustration 11 – MI Cable Design, Dual Termination**



**Illustration 12 – MI Cable Design, Single Termination**

To design an MI cable, the following information must be known.

- Construction style to be used on the pipe
- Cable heat output (same as heat loss)
- Exact cable length, including additional cable for pipe equipment
- Operating voltage

Step 1: Determine the construction style to be used, single or dual termination.

Step 2: Calculate the heat loss in W/Ft from Chapter 1, **Q**.

Step 3: Determine the overall heating cable length, **L**.

Step 4: Determine the operating voltage, **V**.

Step 5: Calculate the necessary resistance per foot,  $\Omega_1/\text{ft}$ .

$$\text{Equation 2.1} \quad \Omega_1/\text{ft} = \frac{V^2}{Q * L^2}$$

This value is the *minimum* resistance value in ohms/foot that will provide the desired heat output to offset the heat loss **Q**, calculated in step 2.

Step 6: Use the Chromalox® resistance tables to select an  $\Omega_2/\text{ft}$  value equal to the value calculated in Step 5. If no value is equal, select the next lower value.

**Note:** Selecting a value *higher* than the value calculated in Step 5 results in heat output below the minimum required heat output and will not offset all of the heat loss of the system.

Step 7: Using the new  $\Omega_2/\text{ft}$  value from Step 6, calculate the actual W/Ft and total watts of the cable.

$$\text{Equation 2.2} \quad W/\text{Ft} = \frac{V^2}{\Omega_2/\text{ft} * L^2} \qquad \text{Equation 2.3} \quad W = W/\text{Ft} * L$$

W/Ft should be equal or greater than the heat loss **Q**. If not, review the calculations for errors.

Step 8: Calculate the current draw, **I**.

$$\text{Equation 2.4} \quad I = \frac{W}{V}$$

Step 9: Select a cold lead length. The standard cold lead length is 7 feet; the shortest length is usually 2 feet.

Step 10: Build the cable catalog number using the Chromalox® format. A typical format is as follows.

Design / Catalog # / Length / Watts / Volts / Cold Lead Length / Cold Lead Size/ Hot-Cold Joint

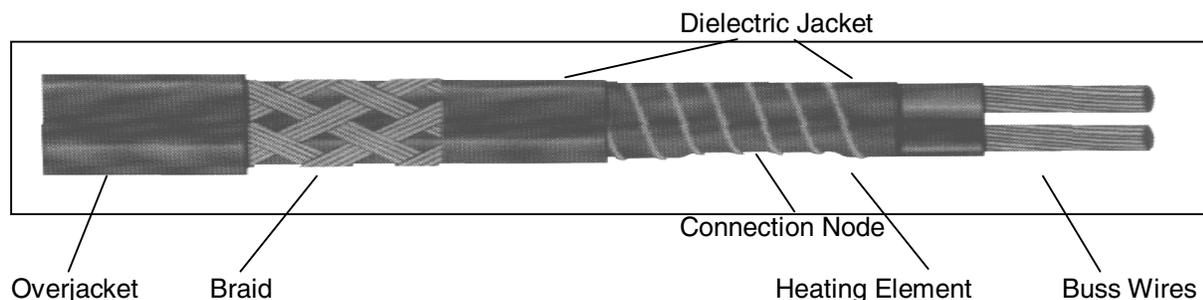
**Summary of Features and Limits – Mineral Insulated Cable**

Features: Rugged, long lasting, fire resistant metal sheathed construction  
 Voltage up to 600VAC  
 Wattage output up to 80 W/Ft  
 Constant output wattage  
 Copper construction: Maintain up to 300°F, Exposure up to 482°F  
 Alloy construction: Maintain up to 1500°F, Exposure up to 1750°F  
 No start-up current

Limits: Series resistance design, entire unit fails if damaged  
 Cannot be used on plastic pipe  
 Cannot be cut to length in field – not available off-the-shelf  
 Cannot be overlapped – will burn out from excessive heat  
 Heater design is complicated compared to other cables  
 Involved installation, MI cable is not as flexible as other systems

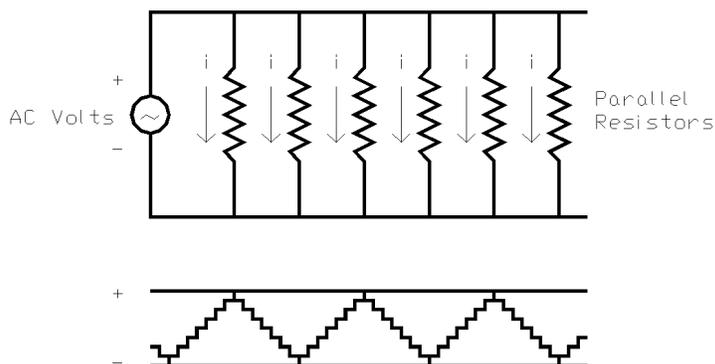
**The Next Step – Constant Wattage.** With all that MI cable had to offer, it had some limitations. Designs are complicated and installation is difficult due to the limited flexibility of the cable. Constant wattage cable (CW) is the next step in heater cable development. It was developed to address some of the limitations of MI cables.

Unlike MI cables, CW cable is constructed of parallel resistor circuits and has a flexible polymer jacket for easier field installation. Cable construction consists of two #12AWG polymer insulated parallel bus wires with a nickel alloy heating element wire wrapped around the insulated bus wires. The entire element assembly is then dielectrically insulated with an additional polymer jacket. To meet current electrical code requirements, CW cables are equipped with a ground braid over the dielectric jacket. In applications where corrosion is a concern, an overjacket of fluorinated ethylene propylene (FEP) can be extruded over the braided cable.



**Illustration 13 – Constant Wattage Construction**

As the nickel alloy wire is spiraled around the insulated bus wires, insulation is removed at specific points to make an electrical connection to the supply voltage. Parallel heating circuits are formed by removing the insulation at the connection nodes on alternating bus wires. Illustration 14 depicts the electrical characteristics of CW cable.



**Illustration 14 – CW Cable Electrical Operation**

CW cable wattage output ratings are dependent on the nickel alloy wire resistance and the amount used between node connections. Consequently, manufacturers standardize the output wattages to specified values. Other features include standard operating voltages of 120V, 240V and 480V and corrosion resistant FEP jackets. FEP jackets limit the effective operating temperatures of CW cable to maintenance temperatures of 250°F and maximum exposure to 400°F. Table 5 lists nominal cable output ratings.

Although CW cable has standard operating voltages of 120V, 240V and 480V, alternate voltages are often utilized in facilities. Applying alternate voltage to a standard CW cable changes the wattage output. The ratio of applied voltage to nominal voltage is called the power factor and is calculated using Equation 2.5. *Limit CW output to 16 W/Ft if applying a power factor ratio to avoid overheating the cable.*

**Equation 2.5**      Power Factor =  $\frac{\text{Applied Voltage}^2}{\text{Nominal Voltage}^2}$

**Table 2 – Typical CW Output Ratings on Alternate Voltages**

Nominal Voltage	Nominal W/Ft	Alternate Voltage Output W/Ft					
		120V	208V	220V	240V	277V	480V
120V	4	4.0	12.0	13.4	16.0	*	*
240V	4	*	3.0	3.4	4.0	5.3	16.0
480V	4	*	*	*	*	*	4.0
120V	8	8.0	*	*	*	*	*
240V	8	2.0	6.0	6.7	8.0	10.6	*
480V	8	*	*	*	2.0	2.6	8.0
120V	12	12.0	*	*	*	*	*
240V	12	3.0	9.0	10.1	12.0	16.0	*
480V	12	*	*	*	3.0	4.0	12.0

\* denotes not recommended

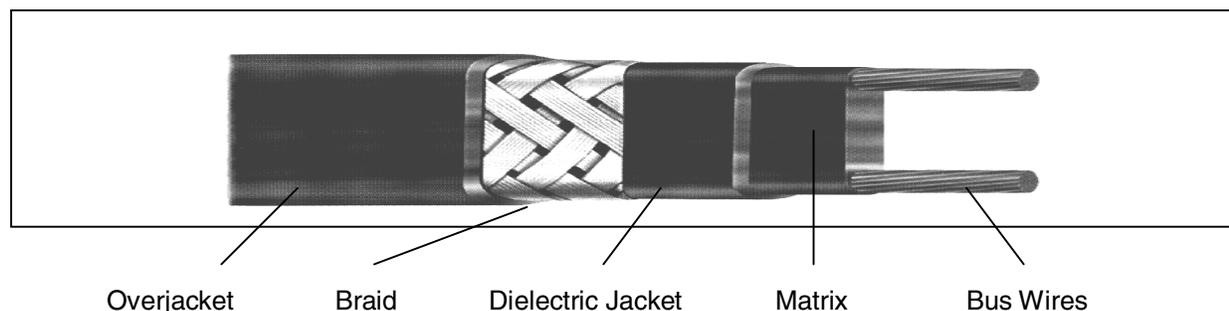
**Summary of Features and Limits – Constant Wattage Cable**

Features: Parallel circuit construction  
 Corrosion Resistant FEP jacket  
 Standard 120V, 240V and 480V operation  
 Maintain up to 250°F, Exposure to 400°F  
 Constant output wattage, easy system designs  
 Cut-to-length in field, simplifies installation  
 No start-up current

Limits: Output limited to 16 W/Ft  
 Excess heat output may overheat pipe contents  
 Cannot be used on plastic pipes  
 Lower temperature limits than MI cable

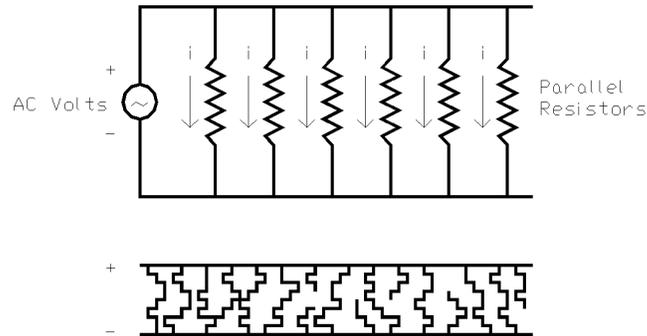
**A New Generation – Self Regulating Cable.** When energized, MI and CW cables provide the same output regardless of pipe or ambient temperatures. In applications where the heat loss is low compared to the cable output, excess cable wattage is absorbed by the pipe system and may overheat the pipe contents.

To overcome the problem of excess heat, self regulating (SR) cable was developed. Rather than using a metal heating element, SR cables utilizes carbon black powder which is electrically conductive. The carbon black is mixed with polymers and extruded in a strip between two parallel bus wires. The polymers respond to temperature changes by microscopically expanding or contracting as temperatures rise and fall. As the polymers expand and contract, the carbon black particles make or break contact with each other. The result is seemingly infinite parallel paths of conductance from one bus wire to the other. The conductive strip, or matrix, is dielectrically insulated with thermoplastic rubber plastic (TPR) or FEP jackets then covered with a ground braid to accommodate current electrical codes.



**Illustration 15 – Self Regulating Construction**

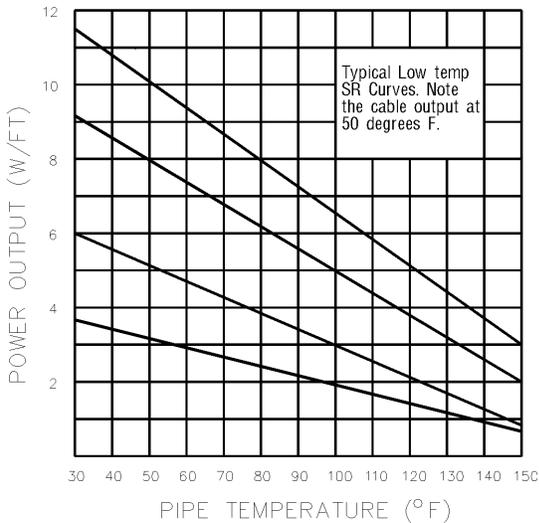
Several benefits emerged with the development of SR cable. The cables' ability to independently respond to local temperatures helps prevent overheating when excess heat is applied. Also, unlike MI and CW cables, SR cable can be overlapped during installation without fear of burnout. Another benefit is the parallel circuitry; the cable can be cut to length in the field without need of factory assistance. Illustration 16 depicts the electrical characteristics of SR cables.



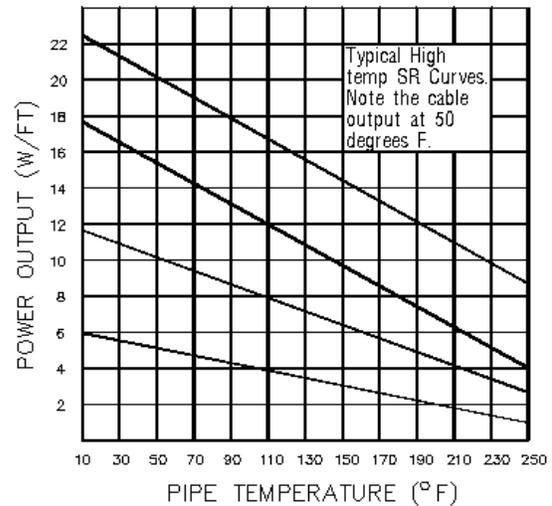
**Illustration 16 – SR Cable Electrical Operation**

Self regulating output curves have a positive temperature coefficient (PTC) slope. A PTC slope indicates that as the temperature of heating cable increases, the outputs decreases and vice versa. Since SR cable output changes, the industry convention is to designate its nominal output wattage rating at 50°F. Graphical representations of low and medium/high cable output curves are illustrated in Graphs 2 and 3.

**Graph 2: Low Temp Output**



**Graph 3: Medium/High Temp Output**

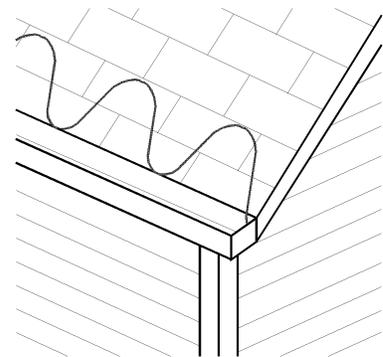


**Industrial SR Cable, Low Temperature.** Generally, low temperature SR cable uses 16AWG bus wires, is offered in nominal watt outputs up to 10 W/Ft and is available in 120V and 240V formulations. The maximum operating temperatures are usually 150°F maintenance and 185°F exposure. The inner dielectric jacket is comprised of TPR insulation. Outer jackets include both TPR for mildly corrosive to FEP for highly corrosive applications. *It is the user's responsibility to determine the correct jacket for the application.*

**Industrial SR Cable, Medium/High Temperature.** Generally, medium/high temperature SR cable uses 14AWG, is offered in nominal watt outputs up to 20 W/Ft and is available in 120V and 240V formulations. A 14AWG bus wire is used to accommodate higher output and subsequent higher operating ampere capacity. Medium/high SR cable has higher operating temperature limits than its low temperature sister products. Due to the polymers used in the construction, the maximum operating temperatures are generally 250°F maintenance and 375°F exposure. The inner dielectric and outer jackets are comprised of FEP insulation for highly corrosive applications. Again, corrosion is the user's responsibility.

**Commercial SR Cable, Freeze Protection.** To address commercial freeze protection applications, Chromalox® has expanded the low temperature self regulating products to include a commercial grade SR freeze protection cable for use on commercial pipes used in parking garages, cooling towers and other non-hazardous applications. These products are similar to the industrial grade SR cables except that they are not approved for hazardous area applications.

**Commercial SR Cable, Snow Melting.** The enormous snowfall amounts in recent winters proved disastrous for building rooftops. Water damage occurs when rooftop snow and ice melts then re-freezes under shingles. Occasionally, structural damage occurs when gutters collapse under the weight of accumulated ice buildup. Consequently, Chromalox® has developed an SR cable to prevent ice buildup in gutters and downspouts.



**Illustration 17**

Snow melting cable is not intended to completely melt the snow and ice from a rooftop. Rather, it is intended to maintain an open path for water to drain during a thaw/re-freeze cycle. Snow melting SR cable uses the same self regulating technology to limit its output to only provide heat when needed. Equipped with UV resistant jackets, SR snow melting cable is designed to provide 5 W/Ft on 120V or 240V when in air at 50°F. When immersed in snow and ice, SR snow melting cable responds by increasing its output to 10+ W/Ft. A typical installation pattern is shown in Illustration 17.

**Inrush.** A side effect of self regulating cables is inrush current. Inrush current is a transient current draw that dissipates over several minutes. The amount of inrush depends on the temperature of the cable when it is energized. Cold cables have higher inrush than warm cables. Since inrush current lasts for several minutes, circuit breakers must be sized to accommodate the additional draw. Circuit protection will be covered in detail in Chapter 5.

### Summary of Features and Limits – Self Regulating Cable

**Features:** Parallel circuit construction  
 Standard 120V and 240V operation  
 Corrosion resistant jackets available  
 Maintain up to 250°F, exposure up to 375°F  
 Variable output, less chance of overheating  
 Low temperature SR can be used on plastic pipes and vessels  
 Cut-to-length in field, easy installation  
 Can be overlapped without burnout

**Limits:** Inrush current can be high, shorter circuit lengths than MI and CW  
 Cannot be used on 480V  
 Lower effective operating temperature range  
 Nominal output wattage is not as accurate as CW or MI

### Summary

**Table 3 - Heating Cable Products Comparisons**

Characteristics	Snow Melting	Comm Low Temp SR	Ind Low Temp SR	Ind High Temp SR	Ind CW	Ind MI
Circuit Construction	Parallel	Parallel	Parallel	Parallel	Parallel	Series
Bus Wire Size	16AWG	16AWG	16AWG	14AWG	12AWG	N/A
Watt Output Range, W/Ft	5	Up to 8	Up to 10	Up to 20	Up to 12	Up to 80
Operating Voltage, VAC	120, 240	120, 240	120,240	120, 240	120, 240, 480	Up to 600
Max Maintenance Temperature, °F	50	50	150	250	320	1500
Max Exposure Temperature, °F	185	185	185	375	400	1750
Terminations installed in Field	Yes	Yes	Yes	Yes	Yes	No
Hazardous Area Approvals	No	No	Yes	Yes	Yes	Yes
Can be Used on Plastic Pipes	No	Yes	Yes	No	No	No
Can Be Overlapped	Yes	Yes	Yes	Yes	No	No
Layout and Design	Simple	Simple	Simple	Simple	Moderate	Difficult
Cable Installation	Simple	Simple	Simple	Simple	Moderate	Difficult

“Comm” denotes Commercial, “Ind” denotes Industrial

**NOTES**

## Chapter 3: Heating Cable Designs

The basic heat loss equations for flat surfaces and pipes can be used in several types of supplemental heating designs that occur in industrial and commercial applications. This chapter will expand the basic heat loss equations to several types of applications. Most applications are divided into three parts - heat loss, cable selection and circuit control and layout. A quick reference guide of applications and equations is listed in Appendix A.

**Heat Loss Designs - Pipes.** The most common application for electric heating cable is to provide supplemental heat for pipes. Rather than constantly using Equation 1.6 to calculate heat loss, Table 4 has been created to simplify pipe heat loss designs. The values in Table 4 are heat loss in W/Ft<sup>2</sup>°F for most pipe sizes and insulation thicknesses. In some cases the design will not be covered in Table 4. Therefore, Equation 1.6 has been listed for use as needed.

To calculate the heat loss of any pipe system, the following information is required:

- Maintenance temperature, T<sub>m</sub>
- Minimum ambient temperature, T<sub>a</sub>
- Pipe size, inches
- Insulation type
- Insulation thickness, inches
- Location
- Maximum expected wind speed
- K-factor of insulation, if not listed in Table 5
- Safety factor

Step 1: Use Table 4 to find Q<sub>p</sub> for the pipe size and insulation thickness.

Step 2: Calculate ΔT.

$$\Delta T = T_m - T_a$$

Step 3: Calculate heat loss, Q.

$$Q = (Q_p)(\Delta T)$$

Step 4: If the application is indoor, multiply Q by 0.9. Indoor applications have little if any heat loss associated with convective losses. Therefore, it is discarded from the heat loss.

Step 5: Adjust Q for wind speed. Add 1% additional heat loss for every MPH over 20MPH expected wind.

Limit the wind speed adjustment to 20%.

$$Q = Q * MPH\%$$

Step 6: Adjust Q for changes in the insulation type and operating temperatures.  $K_{mean} = (K_m + K_a) / 2$

$$Q = Q * K_{mean}$$

Step 7: Add safety factor requirements.

$$Q = Q * SF\%$$

**Table 4: Qp, Heat Loss for Pipes, W/Ft°F**

Pipe Size	Insulation Thickness, Inches							
	1/2	3/4	1	1-1/2	2	2-1/2	3	4
1/2	0.054	0.041	0.035	0.028	0.024	0.022	0.020	0.018
3/4	0.063	0.048	0.040	0.031	0.027	0.024	0.022	0.020
1	0.075	0.055	0.046	0.036	0.030	0.027	0.025	0.022
1-1/4	0.090	0.066	0.053	0.041	0.034	0.030	0.028	0.024
1-1/2	0.104	0.075	0.061	0.046	0.038	0.034	0.030	0.026
2	0.120	0.086	0.069	0.052	0.043	0.037	0.033	0.029
2-1/2	0.141	0.101	0.080	0.059	0.048	0.042	0.037	0.032
3	0.168	0.118	0.093	0.068	0.055	0.048	0.042	0.035
3-1/2	0.189	0.133	0.104	0.075	0.061	0.052	0.046	0.038
4	0.210	0.147	0.115	0.083	0.066	0.056	0.050	0.041
6	0.300	0.207	0.160	0.113	0.089	0.075	0.065	0.053
8	0.385	0.263	0.202	0.141	0.111	0.092	0.080	0.064
10	0.474	0.323	0.247	0.171	0.133	0.110	0.095	0.076
12	0.559	0.379	0.290	0.200	0.155	0.128	0.109	0.087
14	0.612	0.415	0.316	0.217	0.168	0.138	0.118	0.093
16	0.696	0.471	0.358	0.246	0.189	0.155	0.133	0.104
18	0.781	0.527	0.401	0.274	0.210	0.172	0.147	0.115
20	0.865	0.584	0.443	0.302	0.231	0.189	0.161	0.125
24	1.034	0.696	0.527	0.358	0.274	0.223	0.189	0.147

This table includes allowance for 20MPH wind and 10% safety factor and is based on fiberglass insulation at 50°F.

$$Q = \frac{2 \pi (k) (\Delta T) (1.1)}{(40.944) \text{LN}(D_o/D_i)} \text{ W/Ft}$$

**Table 5: Insulation K-Factors**

Temperature, °F	0	50	100	150	200	250	300	350	400
Fiberglass	.23	.25	.27	.29	.32	.34	.37	.39	.41
Calcium Silicate	.35	.37	.40	.43	.45	.47	.50	.53	.55
Urethane	.18	.17	.18	.22	.25	---	---	---	---
Cellular Glass	.38	.40	.46	.50	.55	.58	.61	.65	.70

Example 3.1: Calculate  $K_{mean}$  for cellular glass operating from 160°F to 20°F.

$$\begin{aligned} K_{mean} &= (K_m + K_a) / 2 \\ &= (0.55 + 0.38) / 2 \\ &= 0.47 \end{aligned}$$

Eq 3.1  $Q = (Q_p)(\Delta T)(\%MPH)(K_{mean})(\%SF) \text{ W/Ft}$  for Pipe heat loss.

Once the heat loss is calculated, select a heating cable from the information given in Chapter 2 that has a wattage that equals or exceeds the heat loss. After selecting a cable, the amount of cable must be determined from the pipe and equipment. *Cable output data is available from Chromalox® Product Data Sheets.*

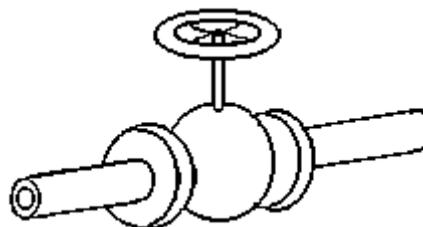
When the cable output exceeds the heat loss, a single pass of cable is applied. However, when the cable output is less than the heat loss, additional cable must be applied by either multiple parallel runs or by spiraling the cable around the pipe in a pattern similar to the classic barber pole style. To calculate the amount of cable required for spiraling, divide the heat loss by the cable output and multiply the result by the pipe length.

Piping equipment such as valves, pumps and supports act as heat sinks and must also be traced. Table 6 includes an equipment allowance chart used to calculate the amount of additional cable required for tracing equipment. The values are based on a ratio of surface areas of one foot of pipe as compared to the heat sink in question of pipes ranging from 1” to 24” diameter. A butterfly valve with an equipment allowance of 2.5 has a surface area 2.5 times greater than one foot of pipe of the same size.

To calculate the cable footage for pipe equipment like the valve shown in Illustration 18, multiply the heat loss by the allowance value and divide the total by the cable W/Ft output. Repeat for each piece of equipment. Sum the totals and add to the pipe cable length to get the total cable footage for the complete pipe circuit.

**Table 6: Pipe Equipment Allowances**

Flange Pair	1.4
Pipe Support	2.1
Butterfly Valve	2.5
Ball Valve	2.8
Globe Valve	4.2
Gate Valve	5.1



**Illustration 18**

$$\text{Extra Cable Allowance} = (Q_{\text{loss/ft}} * \text{AllowanceFactor}) / W/\text{ft}_{\text{cable}}$$

Use these guidelines for determining cable lengths for pipe circuits.

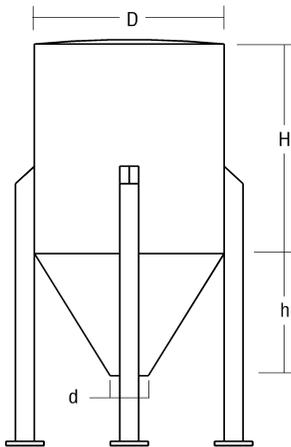
- If cable output > heat loss, use 1 cable pass.  
Equation 3.2a, Cable length = Pipe length
- If cable output < heat loss, choose one of the following.  
Equation 3.2b: Cable length = Pipe length x (Q/Cable output) for spiraled cable  
Equation 3.2c: Cable length = Pipe length x Round up(Q/Cable output) for parallel passes
- Add additional footage for each piece of pipe equipment.  
Equation 3.2d, Cable length =  $\Sigma Q * \text{Allowance} / \text{Cable output}$ , for all equipment

**Heat Loss Designs - Tanks.** In many applications, heat trace cable is used on the outer wall of tanks and vessels to provide supplemental heat. Although pad heaters are used on some tanks, they often concentrate the heat into local areas due to their relatively small size. Contrary to heating pads, heating cable is applied in evenly centered strips around a tank wall over a large surface area. The result - even heat distribution and lower watt density.

The first step in designing a heating cable system for a tank is to calculate the heat loss of the tank surface. A review of Chapter 1 yields the general heat loss equation, Equation 1.4, for flat surfaces. To calculate the heat loss of a tank, the following information is required:

- Maintenance temperature,  $T_m$
- Minimum ambient temperature,  $T_a$
- Tank shape and surface area,  $ft^2$
- Insulation type
- Insulation thickness, inches
- Location
- Maximum expected wind speed
- K-factor of insulation if not listed in Table 5
- Safety factor

The overall surface area of a tank is an essential element in calculating heat loss. Equations for calculating surface areas of several tank styles are given below. Some tanks may have combinations of shapes such as cylindrical with a conical bottom. Solve each section separately then add the areas for each section for the overall surface area.



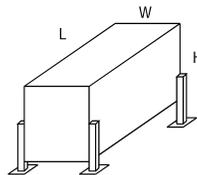
**Illustration 19**  
**Cylinder/Cone**

Cylinder Surface Area =  $\pi D(D/2+H)$ , top and bottom included

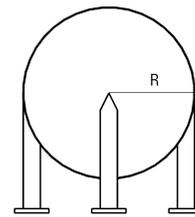
$$\text{Cone Surface Area} = \frac{\pi(D+d)}{2} \sqrt{\frac{(D-d)^2}{4} + h^2}$$

Rectangular Surface Area =  $2[(W*L)+(W*H)+(L*H)]$

Spherical Surface Area =  $4 \pi R^2$



**Illustration 20**  
**Rectangular**



**Illustration 21**  
**Sphere**

Step 1: Use Table 7 to find  $Q_t$  for the insulation thickness.

Step 2: Calculate  $\Delta T$ .  
 $\Delta T = T_m - T_a$

Step 3: Calculate the surface area of the tank,  $A$ .

Step 4: Calculate heat loss,  $Q$ .  
 $Q = (Q_t)(\Delta T)(A)$

Step 5: If the application is indoor, multiply  $Q$  by 0.9. Indoor applications have little if any heat loss associated with convective losses. Therefore, it is discarded from the heat loss.

Step 6: Adjust  $Q$  for wind speed. Add 1% additional heat loss for every MPH over 20MPH expected wind. Limit the wind speed adjustment to 20%.  
 $Q = Q * MPH\%$

Step 7: Adjust  $Q$  for changes in the insulation type and operating temperatures.  $K_{mean} = (K_m + K_a) / 2$   
 $Q = Q * K_{mean}$

Step 8: Add safety factor requirements.  
 $Q = Q * SF\%$

Eq 3.3  $Q = (Q_t)(\Delta T)(A)(\%MPH)(K_{mean})(\%SF)$  Watts for tank heat loss.

Equipment such as ladders, manways and support legs act as heat sinks and increase the overall heat loss of tanks. For each piece of equipment, use Table 8 to calculate equipment heat loss and add to Equation 3.3.

**Table 7:  $Q_t$ , Heat Loss for Tanks,  $W/Ft^{2\circ F}$**

	Insulation Thickness, Inches							
	1/2	1	1-1/2	2	3	4	5	6
<b><math>Q_t</math></b>	0.161	0.081	0.054	0.040	0.027	0.020	0.016	0.013

This table includes allowance for 20MPH wind and 10% safety factor and is based on fiberglass insulation at 50°F.

$$Q = \frac{(k)(A)(\Delta T)(1.1)}{(3.412)(L)} \quad \text{Heat Loss, Watts/hr}$$

**Table 8: Tank Equipment Heat Loss, Watts/°F**

Support Legs	$Q = 0.5 W/^{\circ}F \times \text{number of legs}$
Ladder	$Q = 2.5 W/^{\circ}F \times \text{number of ladders}$
Manways	$Q = 10 W/^{\circ}F \times \text{number of manways}$

*Example 3.2 How many additional watts are required for a tank with four legs and a 70 degree  $\Delta T$ ?*

$$Q = (0.5 W/^{\circ}F)(70^{\circ}F)(4 \text{ legs})$$

$$= 140 \text{ watts plus the overall heat loss from Equation 3.3.}$$

Use these guidelines for selecting a heating cable for tank tracing applications.

- On tanks shorter than 20 feet, trace the bottom half of the tank.
- On tanks taller than 20 feet, trace the bottom third of the tank.
- Space cable between 6 and 15 inches on centers.
- Add extra heat for attached equipment as given in Table 8.
- Attach cable with spot welding pins to the tank to support the cable every three to five feet or as needed. Then apply aluminum tape parallel to the cable circuit.
- The cable can be applied in either spiraled fashion around the tank or in vertical serpentine as shown in Illustration 22.

To calculate the cable wattage required follow these steps.

- 1• The following Equation will determine the maximum amount of cable that can be applied to a tank (all units should be converted to feet) in a serpentine design.

$$Length = \left[ (\pi * Centers / 2) + \%ofCoverage(2H - Centers) \right] * \frac{\pi D}{Centers}$$

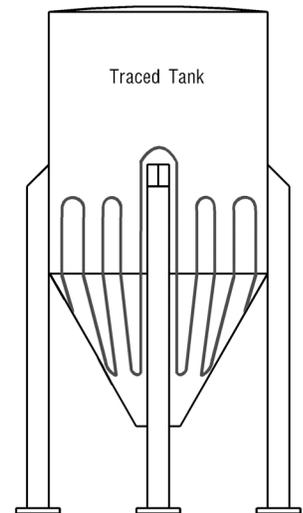
Note that the *Centers* is the cable spacing in feet, *percent of coverage* is the portion of the tank to be traced, *H* is the overall height of the tank, and *D* is the diameter (*πD* may be substituted for the distance around the tank in an alternate tank geometry).

- 1• Select a cable that meets the application requirements.
- 2• Calculate the total watts required for the tank (be sure to add for tank equipment) and divide it by the maximum length calculated in Step 1. Round this number up to the next available cable wattage. Be sure to adjust SR cable wattages for the application process temperature.
- 3• To adjust the cable length required to provide sufficient heat at the specified cable output wattage, divide the total heat loss by the selected cable output wattage from Step 3.

**Heat Loss Designs - Frost Heave Prevention.** Frost heave is damage that occurs to freezer floors when moisture in the soil beneath freezer floors freezes and expands. Excessive expansion buckles the concrete floor slabs and can result in expensive structural repairs. To prevent frost heaving, heating cable is installed in a sand or aggregate bed beneath the concrete slab to maintain moisture temperatures above freezing.

To calculate the amount of heat required to maintain soil temperature above freezing, use Equation 1.4 and Illustration 23 to identify the variables used in the equation. The following guidelines apply when using heating cable for frost heave prevention unless otherwise directed by the customer.

- Space cables on 20" to 30" centers depending on the total wattage required.
- Do not exceed 8 watts per linear foot.
- Use a corrosion resistant jacket with a proper ground path.

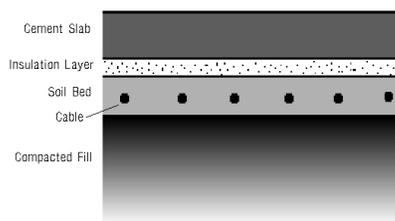


**Illustration 22**

- On long parallel circuits, place “S” style expansion bends in the cable every fifteen to twenty feet to prevent damage to the cable from thermal expansion.
- Control the heating cable with a temperature sensing probe located in the soil bed between two runs of heating cable.
- Use a safety factor of at least 30%. Frost heave prevention is highly variable.

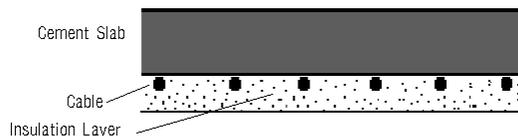
**Floor Warming.** In many commercial buildings, parking garages are located directly beneath the building. Since parking garages are rarely heated, the first heated floor above a parking garage is subject to additional heat loss. To offset these losses, heating cable is occasionally applied to the underside slab of the floor then insulated with rigid foam or fiberglass sheets.

Floor warming designs are closely related to frost heave prevention applications. Use Equation 1.4 with Illustration 24 to calculate the heat loss and amount of cable required. Most of the same guidelines apply to frost heave prevention as in floor warming with this change: space cables on 8” to 16” centers depending on the total wattage required.



A = Total Freezer Area, sq ft  
 $T_m = 40\text{ F}$   
 $T_a =$  Coldest freezer temperature  
 K = Insulation k-factor  
 L = Insulation thickness, inches

**Illustration 23 – Freezer Floor**



A = Total Area, sq ft  
 $T_m = 60\text{-}70\text{ F}$   
 $T_a =$  Minimum ambient, F  
 K = Insulation k-factor  
 L = Insulation thickness, inches

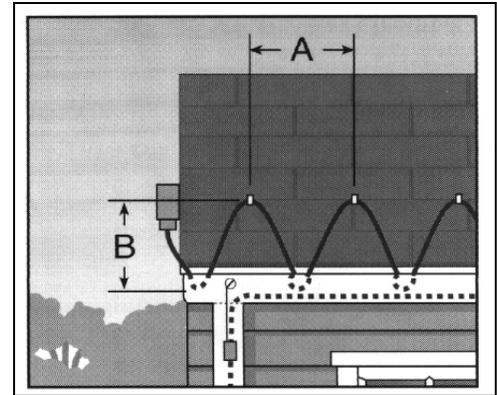
**Illustration 24 – Floor Warming**

**Roof and Gutter Snow Melting.** As stated in Chapter 2, roof and gutter snow melting applications are intended to maintain open drain paths for water. In most cases it is not economically practical to apply enough heating cable on a rooftop to melt all of the snow and ice that accumulates during a snowfall. Instead, heat is applied on exposed roof overhang areas, inside gutters and inside downspouts. The entire downspout must be traced to the ground level opening or until the location where the gutter extends below the frost line. Otherwise the downspout may plug from freezing water.

Designing a roof and gutter snow melting system is a straightforward process. Chromalox® has optimized the wattage for snow melting at 5 W/Ft, therefore, the only cable decision to be made is 120V or 240V operation. It may seem that various W/Ft offerings for roof and gutter snow melting may be required but, it is unnecessary to do so since Chromalox® uses self regulating technology for this product – the cable will provide more heat when needed. In fact, placing too much heat on a rooftop can lead

to damage to asphalt shingles or waterproofing agents. The standard recommendation is to limit the output of snow melting cable to 12 W/Ft when melting snow and ice at 32°F. Consult with local building codes or the authority having jurisdiction to confirm compliance with applicable codes.

Heating cable is installed on the bottom edge of the roof in a serpentine or sine wave pattern and in the gutters and downspouts. Table 9 contains the terms “Overhang”, “Trace Peaks” and “Trace Amplitude”. *Overhang* is the distance the roof extends past the building wall. *Trace Peaks* is the distance between peaks in the sine wave tracing pattern. *Trace amplitude* is the length from the bottom of the roof to the peak of the trace, or, the amplitude of the trace pattern.



**Illustration 25**

To calculate the amount of cable required for a roof and gutter snow melting system, measure the roof edge length, the total gutter length and the total length of downspouts to be traced.

Step 1: Table 9 shows typical values for various roof overhangs; the values can be computed using standard geometry to calculate the sides of triangles. Based on the roof overhang, multiply the roof perimeter by the cable factor shown in Table 9.

Step 2: Add the total gutter length to the length found in step 1.

Step 3: Add the total downspout length to the length found in step 2.

**Table 9 – Overhang Cable Requirements**

Roof Overhang	Trace Peaks	Trace Amplitude	Cable Factor
12 inches	2 feet	18 inches	1.8
18 inches	2 feet	25 inches	2.3
24 inches	2 feet	34 inches	3.0

Although roof and gutter cable is designed for immersion in snow, ice and water, third party approvals do not permit tee splicing roof and gutter cables. An improperly installed tee splice may allow water to enter the electrical connection, which could result in an electrical fire. Consequently, the length of cable required for tracing downspouts could increase. If downspouts occur in the middle of a circuit, double the length of cable required for those downspouts.

### Summary

- Pipes, tanks, freezer floors, floor warming and roof & gutter de-icing are the most common heating cable applications.
- To design a heating cable system, calculate the heat loss, select a cable that meets the design criteria, and determine the amount of cable needed for all equipment.

#### Problem 1: Pipe Tracing

An industrial chemical facility requires heat tracing on a 2" steel line to carry fuel oil 266 feet from an outdoor storage tank to the processing building. To keep the oil fluid, the pipe must be maintained above 140°F and may be pumped at temperatures as high as 215°F. To minimize heat loss in ambient temperatures as low as 20°F, the pipe is insulated with 1-1/2" calcium silicate insulation. Plant maintenance will provide a 240 volt 3 phase, 3 wire feeder for the electric supply. The pipe equipment is in an ordinary (non-classified) area and consists of 2 gate valves and 11 pipe supports.

#### Problem 2: Tank Tracing

A food processing facility requires supplemental heat for a standing cylindrical tank as shown in Illustration 19. The tank is uninsulated, contains corn syrup which must be kept between 110°F and 130°F and is located indoor in a non-classified area which is kept at 60°F to 80°F year round. The plant is limited to a 20 ampere single pole breaker for 120VAC use. Dimensions are as follows: D = 8'6", H = 8'0", d = 3", h = 6'9". Provide a supplemental heating solution for the customer.

#### Problem 3: Frost Heave Prevention and Floor Warming

A commercial food storage company is constructing a new freezer that is to have a frost heave prevention system installed on 24" to 36" centers. The freezer is capable of maintaining -20°F and measures 35 feet long by 24 feet wide. Polystyrene insulation with an R-value of 9 will be installed between the freezer floor and the sand bed. Service to the frost heave system is 480V 3 phase, 4 wire. Provide a solution for the contractor including cable quantity and layout assistance.

#### Problem 4: Roof and Gutter De-icing

A property manager at a commercial building needs to install roof and gutter de-icing cable on a roof top to prevent ice damage from occurring. Field measurements indicate 830 feet of building perimeter, 208 feet of which has an 24 inch overhang. Also, the two story building consists of 6 downspouts having a total length of 150 feet. Spare breakers in a 240V service panel are available.

## Chapter 4: Circuit Layout and Controls

Up to this point this training manual has treated all of the examples and problems as one continuous circuit. The next step in designing heat trace applications is selecting the proper control scheme. Controls range from simple ON/OFF mechanical thermostats to sophisticated microprocessor based control and power distribution panels. Chapter 4 will explain circuit analysis, controls, electrical circuit protection, and cable accessories.

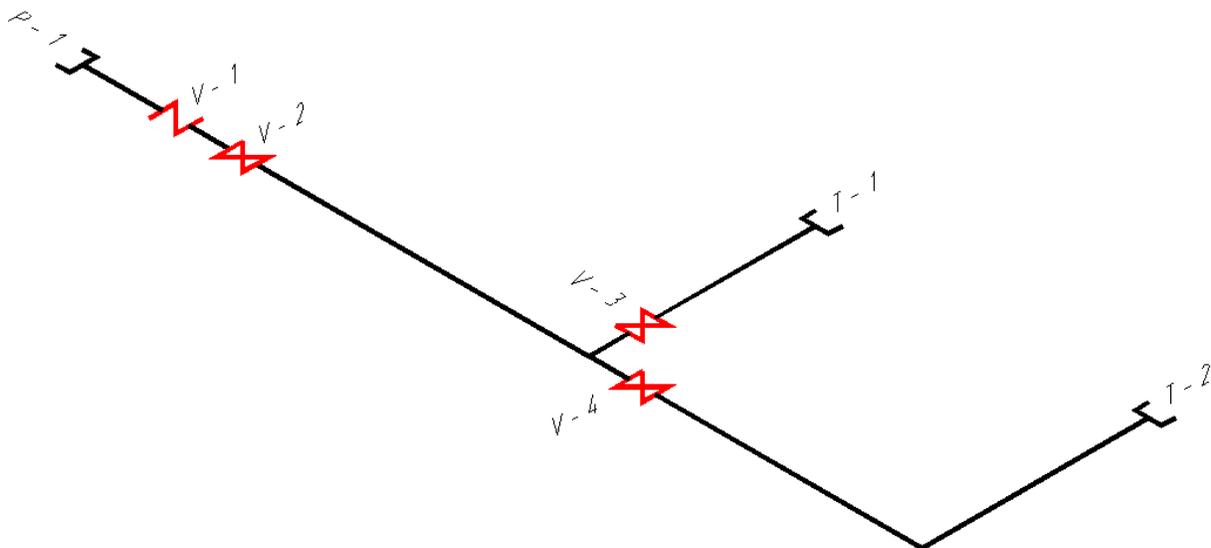
### Part I: Flow Paths and Circuit Analysis

In order to properly design heat trace controls, one must first understand the basics of how fluid flows in a pipe. Generally, moving liquid in a pipe does not require heat because little heat is lost during the short residence time. Conversely, stagnant fluids lose heat that must be replaced for temperature to remain constant.

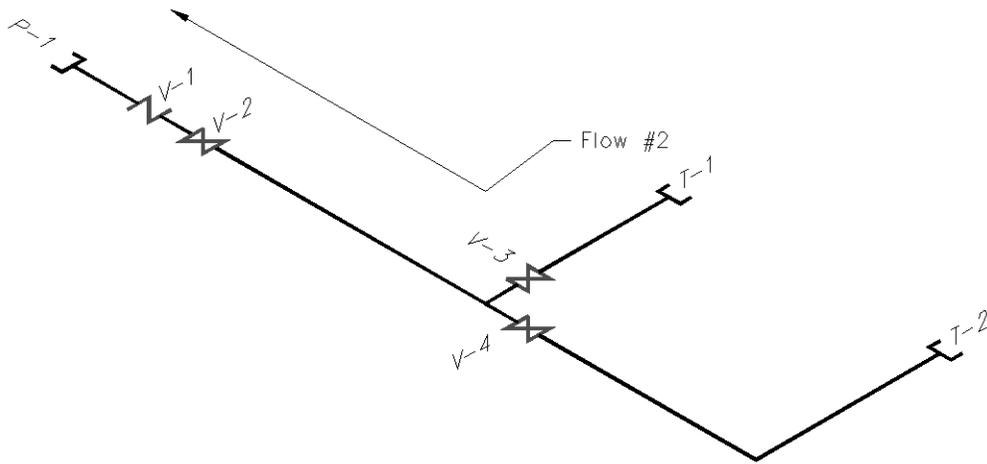
**Process Maintenance, Individual Circuits.** Illustration 26 shows piping for two tanks, four valves and one pump from a loading station. When pump P-1 is activated, fluid is drawn from Tank T-1 or T-2 depending on which valves are open; V-1 is a check valve that prevents backflow and V-2 is the primary shutoff valve.

Possible flow conditions are:

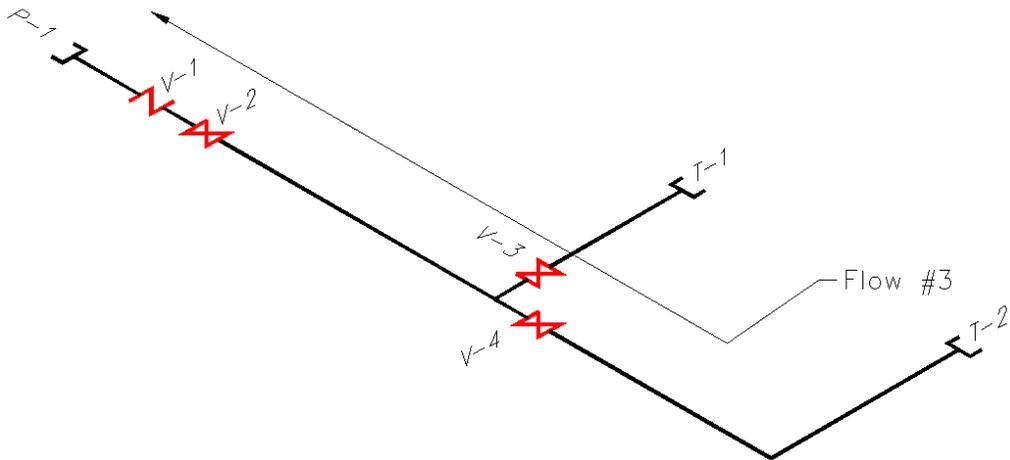
- |                                     |                         |
|-------------------------------------|-------------------------|
| 1. If P-1 is OFF, V-2 CLOSED        | RESULT: Illustration 26 |
| 2. If P-1 ON, V-2 and V-3 OPEN      | RESULT: Illustration 27 |
| 3. If P-1 ON, V-2 and V-4 OPEN      | RESULT: Illustration 28 |
| 4. If P-1 ON, V-2, V-3 and V-4 OPEN | RESULT: Illustration 29 |

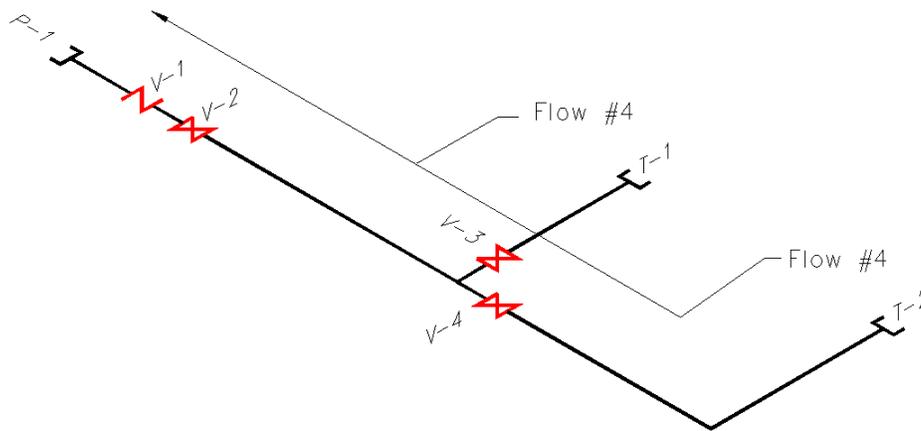


**Illustration 26: P-1 OFF, V-2 CLOSED. RESULT: No Flow**



**Illustration 27: P-1 ON, V-2 and V-3 OPEN. RESULT: Draw from T-1**



**Illustration 28: P-1 ON, V-2 and V-4 OPEN. RESULT: Draw from T-2****Illustration 29: P-1 ON, V-2, V-3 and V-4 OPEN. RESULT: Draw from T-1 and T-2**

An analysis of illustrations 26-29 reveals the following information on each system.

- Illustration 26 shows that the fluid in all of the pipes is stagnant. Therefore all of the pipes and valves require heat trace.
- Illustration 27 has a flow path from Tank T-1 to the pump. The pipe from valve V-4 to Tank T-2 is stagnant and requires heat trace.
- Illustration 28 has a flow path from Tank T-2 to the pump. The pipe from valve V-3 to Tank T-1 is stagnant and requires heat trace.
- Illustration 29 has flow throughout all pipes. No supplemental heat is required.

Fluid stagnation can occur under multiple conditions in this pipe system. Consequently, all pipes that could become stagnant must be individually controlled. In addition, pipes that are part of common flow paths should be controlled individually. While it may be convenient to associate common pipes with a flow path, it is not recommended because it could lead to unpredictable control results and is not energy efficient. **Every flow path circuit receives a pipe wall sensor and is controlled separately.**

#### Example 4.1

*Identify all control circuits for the pipe used in Illustration 26.*

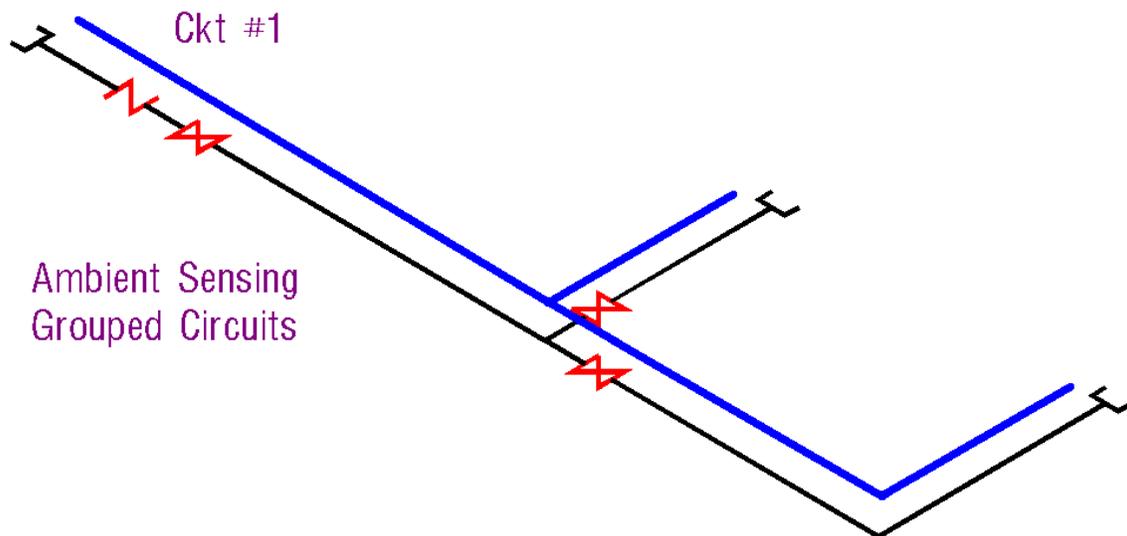
*Illustration 30 shows a breakdown of the different circuits for this pipe configuration. The circuits consist of the common pipe for tanks T-1 and T-2 and the individual pipes for tank T-1 and T-2. There are 3 total circuits for this pipe configuration.*



**Freeze Protection, Grouped Circuits.** Individual circuit control is essential in applications where the contents of the pipe must be maintained at temperatures well above freezing. Otherwise the contents solidify and plug the pipe. For example, caustic soda solutions will form precipitates in pipes if the temperature falls below 65-70°F. What about applications where the only concern is to keep the pipe contents from freezing to prevent damage to pipes and equipment?

When individual flow path analysis is not essential, the circuits can be grouped together and controlled by a common ambient sensor. Using ambient sensing control, it is possible for the heating cable to be energized even though the pipe contents are well above freezing temperature. Since this technique does not sense the pipe temperature, the pipe contents must be able to withstand wider temperature variations.

Ambient sensing is similar to deadlegging except that the sensor responds to air temperature – not a pipe wall. Also, ambient sensing control can be used to energize many pipe circuits that are subject to freeze protection, not just those pipes in the immediate vicinity. The pipe system from Illustration 26 has been re-designed to incorporate ambient sensing control and is shown in Illustration 32.



**Illustration 32: Flow Path/Circuit Analysis – Ambient Sensing**

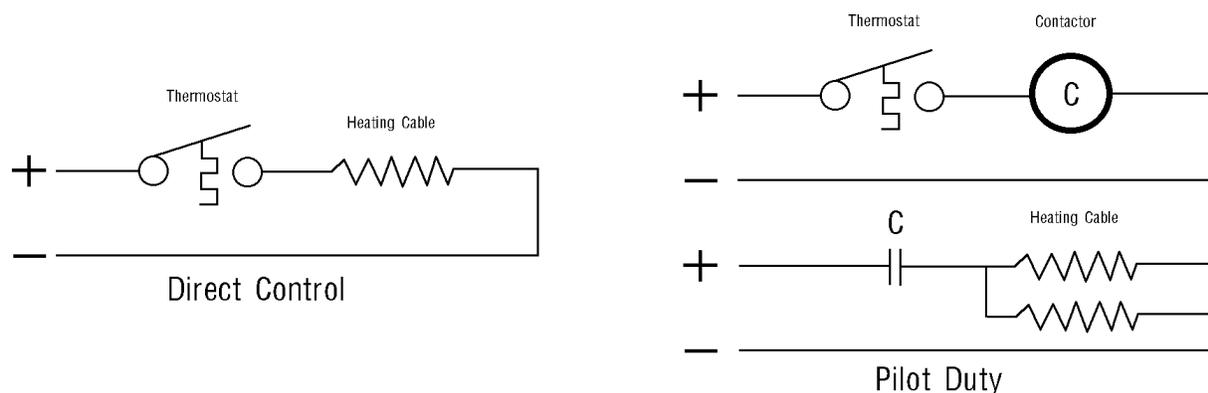
### Part 2: Controllers, Ambient and Pipe Wall Sensing

Once circuit analysis has been completed, a control scheme can be designed. Heat trace controls are usually locally mounted mechanical thermostats with integral contacts or electronic, remotely switched units. The most common control techniques are discussed in detail in the following sections.

**Ambient Sensing.** Ambient sensing thermostats are used to switch power ON when the temperature falls below the setpoint, usually set between 40-50°F. Ambient sensing thermostats use a fluid filled probe to activate the mechanical switch. The probe, usually 4-6 inches long is placed directly in the air to sense surrounding temperatures. Locally mounted ambient sensing thermostats are placed directly on the pipe at the power connection point. Many types of ambient sensing thermostats have an integral contactor capable of switching 20 to 30 amperes.

Ambient sensing thermostats can also be used as pilot duty for large freeze protection systems. Rather than switch power directly to the heating cable, the thermostat contactor is used to energize holding coils in a power distribution panel. The result is that one thermostat can switch thousands of feet of freeze protection cable.

Chromalox® offers several types of ambient sensing thermostats for use in freeze protection systems. The units are housed in a NEMA 4X or 7 enclosure for mounting outdoors, and can switch up to 30 amperes depending on the model. Refer to Chromalox® Product Data Sheets for additional information. Illustration 33 shows the electrical schematics for direct and pilot duty use of an ambient sensing thermostat.



**Illustration 33: Ambient Sensing Control Schemes**

The left hand circuit in Illustration 33 shows a thermostat wired for direct control. When the thermostat closes, power is applied to the heating cable through the thermostat switch. The right hand circuits in Illustration 33 depicts a thermostat being used to energize a holding coil for a contactor. When this thermostat closes, power is applied to the contactor coil. The coil closes the contacts and supplies power to both circuits.

**Pipe Wall Sensing.** Like ambient sensing thermostats, pipe wall sensing thermostats are used to switch power ON when the pipe temperature falls below the adjustable setpoint. Pipe wall sensing thermostats use a fluid filled bulb and capillary to activate the mechanical switch. The bulb, usually 6-12 inches long is placed directly on the lower side of the pipe at least 90 degrees away from heating cable placed on the pipe. Like ambient sensing devices, integral switches are rated for up to 30 amperes.

Pipe wall sensing thermostats are used in process maintenance applications where temperatures must be kept at 60°F and higher. Most pipe wall sensing thermostats have adjustable setpoints and are housed in a NEMA 4X enclosure. Refer to the Chromalox® Product Data Sheets for further information, including Hazardous Area approvals.

Unlike ambient sensing thermostats, it is less practical to utilize a pipe wall sensing thermostat for pilot duty. Since pipe wall sensing thermostats control only one pipe flow path circuit, it generally cannot switch more than one remote contactor for multiple circuits. There are exceptions to this, however.

In cases where several parallel or end-to-end heating cable circuits are on the same pipe and share a common flow path, a pipe wall sensing thermostat can be used to energize all of the circuits at one time. Also, in cases where a heating cable circuit exceeds the ampacity of the pipe wall thermostat, the thermostat can be used to activate a higher rated contactor. Tank process maintenance tracing is another example of multiple circuits having the same temperature requirements. One pipe wall, or in this case, tank wall sensing thermostat can be used to switch the entire tank tracing system ON when heat is required.

On larger heat trace systems, facilities may require a more sophisticated electronic control system. On these systems, a separately housed power connection box and RTD (Resistance Temperature Detector) replace the thermostat. The sensor is wired to a remote electrical panel where the controller and power switching devices are located. Remote controlled systems generally offer greater control and alarm features and simplify standard maintenance programs.

Electronic controls range in variety from single to multi-point and analog to microprocessor based. Most have digital temperature indication to provide visual feedback on process conditions. In addition, many electronic controllers incorporate alarm features such as high and low temperature alarms, sensor failure alarms and pilot lights to indicate circuit and alarm status. Many units are equipped with digital communications to simplify programming and operation.

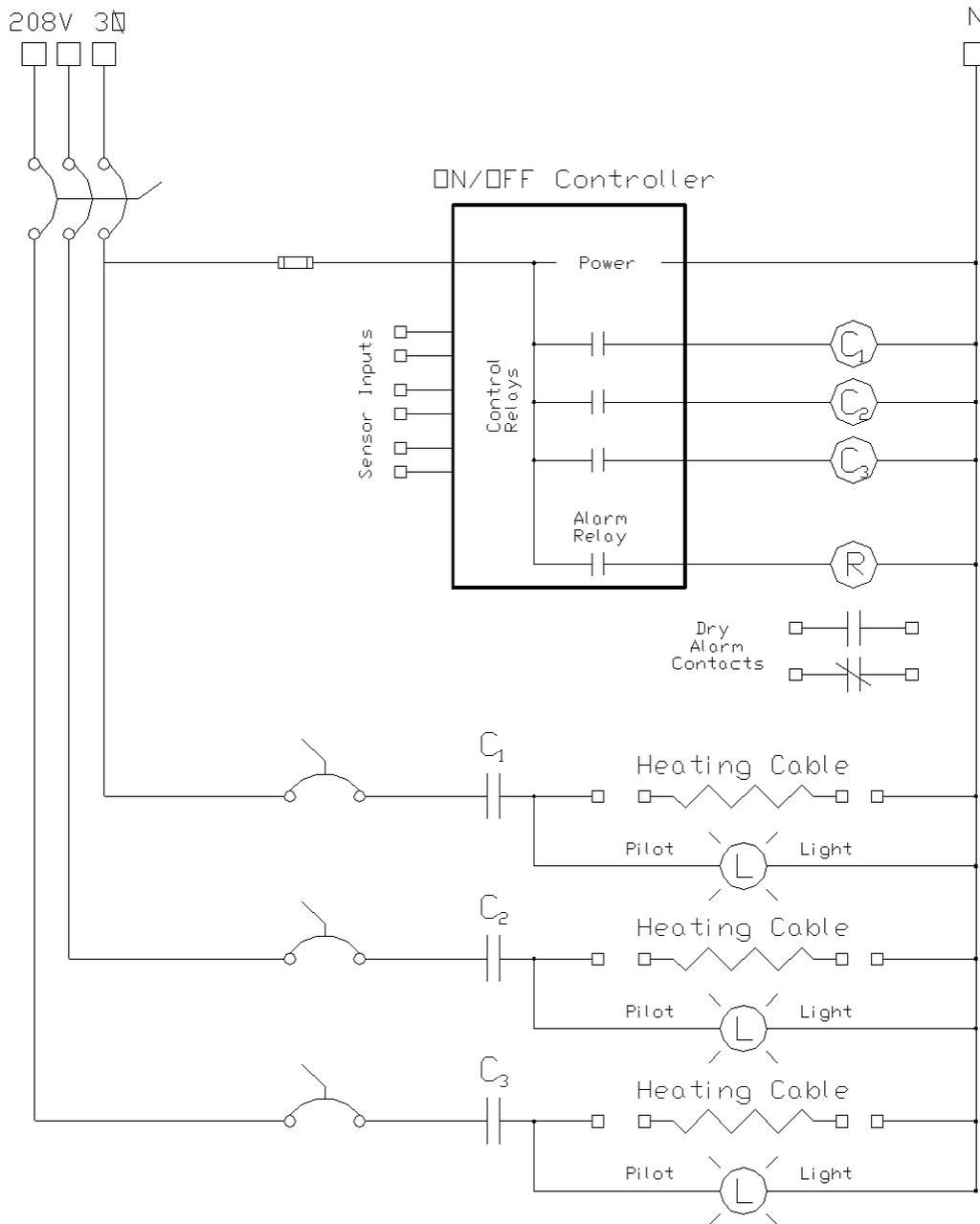
Today, most heating cable suppliers offer sophisticated microprocessor based controllers. These units accept several sensor types, can be used as an ON/OFF, proportional, or PID controllers. These types of controllers are housed in control/power distribution panels to create a complete heat trace package.

The electrical control scheme for remote control sensing is similar to the right hand picture in Illustration 33 except that the contactor is switched by controller logic rather than a mechanical pressure switch. Because heat trace cables are low heat output products, ON/OFF control using contactors is usually sufficient. However, conditions may exist where faster cycling is required to prevent overheating pipe or vessel

contents. Consequently, the contactors may be replaced by solid state relays (SSR) to enable tighter control on a cable's heat output.

Remote control systems are custom built to meet specifications or address a particular control requirement. When designing a remote panel control system, ask the following questions.

- 1• What NEMA rating panel is required?
- 2• What is the incoming supply voltage to the panel (voltage, phase, # wires)?
- 3• What is the heating cable voltage?
- 4• How many circuits are required?
- 5• What type of control scheme or controller will be used?
- 6• What size branch circuit protection is required?
- 7• What type of power switching devices are required (contactors, SSRs, triacs)?
- 8• What alarm conditions are to be monitored?
- 9• Are pilot lights required to indicate circuit or controller status?
- 10• What spare capacity is required?



**Illustration 34: Logic Diagram for Typical Heat Trace Panel**

A ladder logic diagram for a three circuit panel is shown in Illustration 34. This panel consists of a main disconnect breaker, branch circuit breakers, an ON/OFF multi-point controller, power contactors, visual indication of circuit status and a dry contact for a common alarm circuit. In this Illustration the primary voltage supply is 208V, 3 Phase, 4 wire and the cable voltage is 120VAC.

Part 3: Circuit Protection. Part 2 introduced the topic of circuit protection. **WARNING:** when electrical equipment fails, the equipment may draw excessive current and could create a fire or shock hazard. Fuses and circuit breakers are designed to interrupt electrical service to equipment when the ampacity rating of the device is exceeded. Care must be taken when sizing circuit protection for electrical equipment; undersizing results in nuisance tripping and poor performance while oversizing results in excess current draw and possible fire or shock hazards.

The National Electrical Code book (NEC®), published by the National Fire Protection Association (NFPA®), is a nationally accepted reference document that encompasses electrical wiring and safety practices. Various articles address basic safety and wiring practices common to many types of electrical equipment. Within the 1996 edition of the NEC®, Articles 426 and 427 address electrical heat trace. Article 426 deals with snow melting while Article 427 focuses on pipes and vessels.

Paragraphs 426-4 and 427-4 of the NEC® describe one of the most basic and essential requirements for electric circuits - how to size circuit protection. It states that a circuit protection device must be rated for 125% of the total load of the equipment in question. For example, an electrical circuit that draws 9.6 amperes must be protected by a device rated for a minimum of 11.25 amperes. Since it is impractical to build a circuit protection device to handle exactly 11.25 amperes, circuit protection manufacturers build devices with standard incremental ranges of operation. The most common ratings are 10, 15, 20, 25, 30, 40, and 50 amperes, single, two or three pole. For the example given above, the best choice is to use a 15 ampere rated device.

Two other paragraphs in the 1996 NEC® worth noting for heat trace are 427-22 and 427-23. Article 427-22 states that all electric heat trace cables must have a metallic ground path capable of supporting full load amperage in the event of cable failure, regardless of area classification or pipe construction. In other words, a ground path is always required on all electric heating cables.

Article 427-23 states that all electric heat trace circuits must be protected by ground fault indicating devices. Although the code does not specify whether the ground fault devices be rated for personnel or equipment protection, manufacturers generally recommend the use of 30mA equipment protection devices. **NOTE:** It should be noted that a 6mA maximum trip value is required for personnel protection. This, however, is typically not practical due to leakage current common in heat trace cable. **Ground fault protection is required for all heat trace applications regardless of whether the cable is installed in Ordinary or Hazardous locations.**

To select the proper circuit protection, the current draw must be known for each circuit. Current draw is calculated by multiplying the circuit footage by the cable watt per heat output to get the circuit wattage. Then, divide the circuit wattage by the circuit operating voltage. Remember, for self regulating cables, use the watt per foot heat output at the maintenance temperature, not the nominal watt output as measured at 50°F.

Once the circuit amperage is known, circuit protection is sized by multiplying the circuit amps by 125% per NEC® code. Select the circuit protection device that has the next higher rating beyond the 125% load. Use caution when applying larger breakers to long circuits. While it may be possible to apply long heat trace circuits on a 40 or 50 ampere breaker, most heating cables have maximum circuit lengths and manufacturing specifications that limit the overall length a circuit may be run.

#### Example 4.3

Calculate the amount of current draw for 200 feet of an 8 W/Ft CW cable maintaining 100°F. The cable is operating on 120VAC. Calculate the current draw for the same 200 foot circuit if a 10 W/Ft SR cable is used instead. What size overcurrent protection is required for each circuit?

#### Constant Wattage Solution:

$$\begin{aligned} \text{Circuit Watts} &= \text{footage} * \text{watt/foot output} \\ &= (200 \text{ feet}) * (8.0 \text{ W/Ft}) \\ &= 1600 \text{ watts} \end{aligned}$$

$$\begin{aligned} \text{Circuit Amps} &= \text{Circuit Watts/Voltage} \\ &= 1600 \text{ Watts}/120\text{Volts} \\ &= 13.3 \text{ amperes} \end{aligned}$$

$$\begin{aligned} \text{Breaker Rating} &= \text{Circuit amps} * 1.25 \\ &= (13.3 \text{ amps}) * 1.25 \\ &= 16.63 \text{ amp rating. The next higher rating is a 20 ampere breaker} \end{aligned}$$

#### Self Regulating Solution:

$$\begin{aligned} \text{Circuit Watts} &= \text{footage} * \text{watt/foot output} \\ &= (200 \text{ feet}) * (6.5 \text{ W/Ft}) \\ &= 3600 \text{ watts} \end{aligned}$$

$$\begin{aligned} \text{Circuit Amps} &= \text{Circuit Watts/Voltage} \\ &= 3600 \text{ Watts}/120\text{Volts} \\ &= 10.8 \text{ amperes} \end{aligned}$$

$$\begin{aligned} \text{Breaker Rating} &= \text{Circuit amps} * 1.25 \\ &= (10.8 \text{ amps}) * 1.25 \\ &= 13.5 \text{ amps. The next higher rating is a 15 ampere breaker. THIS ANSWER IS} \\ &\quad \text{WRONG. READ ON TO FIND OUT WHY.} \end{aligned}$$

The breaker rating solution for the self regulating case in Example 4.3 states that the answer is wrong. To understand the reason for the error in calculating circuit protection for self regulating cables, two definitions for current must be introduced: startup current and steady state current. Startup current is a dissipating current drawn while a cable's heating element is changing resistance when the cable is first energized. Steady state current is the current drawn by heating cables once the cable's resistance has stopped changing. Constant wattage and mineral insulated cables use metal heating elements, which change very little as heat is generated. Consequently, these types of cables do not exhibit startup current.

By their nature, self regulating cables are specifically designed to change their resistance values. When a self regulating cable is first energized, the polymer core

heats up quickly and changes its resistance. The startup current draw decreases quickly as the polymer core reaches thermal equilibrium. Once the cable has thermally stabilized, it draws a steady current. Startup current can be 2 to 3 times higher than the steady state current and can last for several minutes. The good news is that roughly 70% to 80% of the startup current dissipates within the first minute or two.

Since self regulating cables exhibit startup current which is a temperature sensitive phenomenon, it is difficult to know the exact amount of current draw that will be drawn when a cable is energized. Therefore, Chromalox® has created tables for all of the self regulating cables to assist in selecting the proper breaker rating. These tables are found on the PDS data sheets for each cable type and list the maximum allowable cable footage that can be placed on each breaker rating shown. One final note about circuit protection for self regulating cables: High Magnetic or Thermal breakers for self regulating cables have a greater capacity to absorb startup current without nuisance tripping while maintaining adequate steady state current protection.

*Example 4.3 continued*

*Revisiting example 4.3, the PDS data sheet for Chromalox® SRL indicates that a 15 ampere breaker is only capable of supporting 55 feet of SRL10-1C at 50°F, 45 feet at 0°F and a 35 feet at -20°F. If the customer is using 15 amp breakers and the startup temperature is 50°F, the 200 foot circuit will have to be split into 4 circuits.*

**Part 4: Circuit Layout and Bill of Materials.** When flow paths have been established, a control scheme has been decided, and circuit lengths have been determined, the next step is to layout circuits and assemble a bill of materials for each circuit.

Before assembling a bill of materials, a quick review of the components that go into building heat trace circuits is in order. There are two classes of heat trace accessories: termination kits and attachments. Termination kits are used to terminate a cables' electrical connections. They consist of power connection boxes, splice kits, tee kits, and end seals. Attachments are used to fasten cable and termination kits to the pipe or vessel equipment. These consist of fiberglass tape, pipe straps, mounting plates, and other ancillary items. *Consult the proper data sheets for details on each accessory.*

## TERMINATION KITS

**Power connection Kits.** Used to connect power to heating cable. Suitable for NEMA 4X and Division 2 hazardous area applications.

**Splice Kits.** Used to join two cables end to end, usually to extend a circuit. Suitable for NEMA 4 and Division 2 hazardous area applications.

**Tee Kits.** Used to join three cables at one point, usually to permit tracing at a pipe tee point. Suitable for NEMA 4 and Division 2 hazardous area applications.

**End Seal Kits.** Used to electrically isolate bus wires from the end of a circuit. Suitable for NEMA 4 and Division 2 hazardous area applications.

## ATTACHMENTS

**Fiberglass Tape.** To affix heating cable to pipe and piping equipment. The tape is banded around the pipe at twelve inch centers.

**Aluminum Tape.** To improve heat transfer from heating cable to pipe wall. Chromalox® recommends that aluminum tape be used when low temperature self regulating cable is applied to plastic pipes and vessels and on constant wattage applications using 8 W/Ft and higher cable.

**Straps.** Stainless steel straps to fasten termination kits to pipe. Also suitable for fastening controls to pipes.

**Conduit Connections.** To provide a connection point between termination boxes and power supply conduit.

**Caution Labels.** Used to advise personnel that an electric cable is installed beneath insulation. These are applied over the insulation or weather barrier at 10 foot centers, can be on alternate sides of insulation.

To assemble a bill of materials, determine the length of cable required depending on the heat loss, cable selection, and equipment being traced. Then, determine the number of circuits required for the overall cable length calculated and the circuit protection rating. For each heat trace circuit, use a power connection box with the proper size pipe strap, the correct amount of fiberglass tape to affix the cable to the pipe, and an end seal fitting. Consult Product Data Sheets for quantities of Attachment Accessories required. For every tee kit used, remember to add an additional end seal fitting. If local controls are used, add the controller next to the power connection box. The following example demonstrates a complete bill of materials.

### Example 4.4

*Create a bill of materials for the pipe shown in Illustration 32. The 150 foot long 2" pipe is to be maintained at 50°F in a -10°F ambient, is insulated with 1" fiberglass, contains water and is located in an ordinary area. Assume 10% safety factor. Local ambient sensing controls are required for use on 120V 20-ampere breakers.*

*Step 1: Using Eq. 3.1, calculate heat loss.*

*Q = 4.37 W/Ft*

*Step 2: Select a cable and quantity. Valve type unknown. Use Gate valve.*

*Use SR cable 5 W/Ft  
168 feet required*

*Step 3: Layout flow paths. Refer back to Illustration 32.*

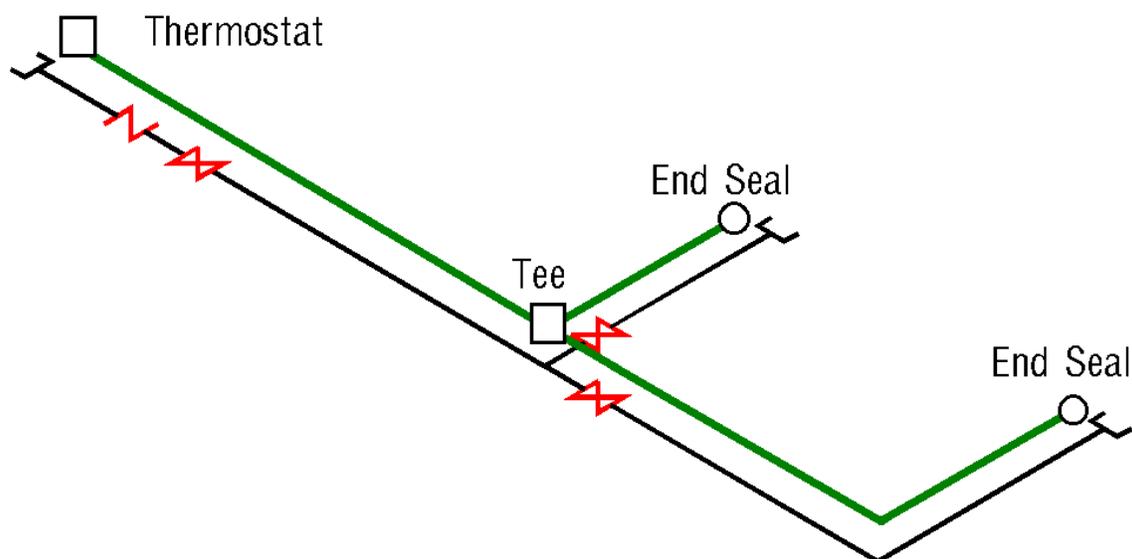
*One circuit needed.*

*Step 4: Calculate current draw and circuit protection for each circuit.  
Using Chromalox® cable as an example, up to 200 feet of 5 W/Ft  
SR cable can be applied to one 20 amp breaker.*

*I = 7.0 amperes  
1 circuit required*

Step 5: Determine bill of materials.

<i>Product</i>	<i>Quantity</i>	<i>Where used</i>
5 W/Ft SR Cable, 120V	168 feet	Along pipe wall to maintain pipe temperature
Ambient sense T'stat	1 ea.	At beginning of circuit in top left corner
Tee kit	1 ea.	At junction of valves V-3 and V-4
End seal kit	2 ea.	At end of circuits, near Tank T-1 and T-2
Strap	2 ea.	At T'stat and Tee location to affix boxes to pipe
Fiberglass tape	2 rolls	Banded on 12" centers to affix cable to pipe
Conduit connections	1 ea.	At thermostat to apply conduit to box
Caution labels	15 ea.	Over insulation on 10 foot centers.



**Illustration 35: Bill of Materials Layout for Example 4.4**

If a remote thermostat or controller was required for example 4.4, the thermostat would be replaced by a power connection box and a remote sensor would be installed near the beginning of the circuit.

**A Roof and Gutter Bill of Materials.** Power connection, splice, and end seal termination kits for roof and gutter applications are similar to those used on pipe and vessel applications. Keep in mind that 3-way tee splices are not permitted. The attachment accessories for roof and gutter applications must be suitable for securing heating cable to the rooftop as well as downspout entry points. Roof clips and downspout supports are additional kits introduced for use on snow melting cables.

## ATTACHMENTS

**Roof Downspout kit.** Use to support heating cable entry point into downspout. Use one per downspout.

**Roof Clip kit.** Use to attach heating cable to rooftop in sinusoidal pattern. One 5 pack of double clips accommodates 7 linear feet of overhang.

## Summary

**The principals discussed throughout this chapter apply to nearly all heat trace circuits. There is no difference in performing a design and bill of materials for one or one hundred heating cable circuits. The key to successful heat trace designs is to have good organizational skills to keep track of the heat loss solution, cable selection and bill of materials for each circuit designed.**

**These same principals apply to pipes, vessels, slabs, and roof and gutter installations. Practice and experience are the two best ways to sharpen these skills.**

- Individual flow path circuits are required when the contents of a pipe or vessel must be maintained well above ambient temperatures to prevent solidification or the formation of precipitates.
- Individual flow path circuits can be grouped together when the contents must only be kept above 32°F freezing.
- Dead legging can be used to group complex, short pipe circuits into one circuit by placing the sensor on the pipe that is used least often. By-pass circuits are normally used.
- There are exceptions to the general rules for identifying control circuits. Analyze each pipe system and discuss control options with the facility owner when possible.
- Ambient sensing thermostats can be used to directly control single or multiple heating cable circuits up to the thermostat's ampacity limit. They can also be used as pilot duty controllers to switch power contactors in distribution panels.
- Pipe wall thermostats are used in process maintenance applications where maintenance temperatures are normally above ambient temperatures or where individual flow paths must be maintained separately. Although not generally used as pilot duty devices, there are applications where multiple circuits can be switched using a single process maintenance controller.
- More sophisticated electronic and microprocessor controllers are available to provide accurate, multiple circuit heat trace control while providing alarm capability. In most cases, electronic controls are used as pilot duty devices in conjunction with power distribution panels.

- When sizing circuit protection, always comply with manufacturer's instructions and specifications. Consult the NEC® code book for the latest wiring and safety practices for heating cable.
- There is usually more than one solution to selecting a bill of materials for a heat trace circuit. Be sure to consult with product data sheets for the latest information and specifications on all heat trace cables and accessories.

Problems:

1. Using 20 ampere single pole breakers, calculate the minimum number of circuits required to protect a 1,200 foot pipe run traced with 120V, 8 W/Ft constant wattage cable. Repeat for 1,200 feet of 120V, 8 W/Ft self regulating cable if the maintenance temperature is 50°F.
2. Assemble a bill of materials for example 4.1 assuming the same heat loss conditions exist as were used in example 4.4. In this case, local pipe wall controls are required.
3. Create a bill of materials for Chapter 3, Problem 4. Use 20-ampere two pole breakers for circuit protection.

## Chapter 5: Hazardous Area Considerations

Heating cable is used in industrial and commercial facilities for a variety of heat loss replacement applications. In many cases, heating cables used in industrial applications must be approved for use in hazardous, classified areas. To obtain approvals for hazardous area use, heating cable and its associated components are put through extensive testing by independent companies. In addition to approvals, organizations exist to oversee the guidelines under which heating cable is manufactured, tested, designed and installed. Chapter 5 focuses on topics surrounding hazardous areas.

**The Basics, Non-hazardous versus Hazardous.** The best way to differentiate between these two areas is to explain what constitutes a hazardous area. A hazardous area is defined as any area where the presence of explosive gases, vapors, dusts, or fibers are present, either under normal operating conditions or in unusual circumstances. Consider the following overview of NFPA® classifications for defining hazardous areas. For complete definitions, refer to Article 500 of the 1996 NEC® handbook.

Class I. Locations where sufficient quantities of flammable gases or vapors are or may be present to produce explosive or ignitable mixtures.

Class II. Locations where sufficient quantities of combustible dusts are or may be present.

Class III. Locations where sufficient quantities of easily ignitable fibers are or may be present.

Division 1. The presence of the hazardous condition exists during normal facility operation.

Division 2. The presence of the hazardous condition only exists under unusual or upset conditions.

Groups are used to further fine tune hazardous area designations. Groups A, B, C, and D are used to classify gases and vapors based on the amount of pressure and heat generated during an explosion. Groups E, F, and G are used to classify combustible dusts based on resistivity.

**WARNING:** Classifying an area is NEVER the responsibility of heat trace designers or associated personnel. Authorized personnel of the facility where the heating cable will be installed must ALWAYS give the area classification. Classification is a complex process that has grave consequences if performed incorrectly.

**Sheath Temperatures.** A fundamental concern in placing heating devices into hazardous areas is the possibility of an explosion or fire. Subsequently, the cable's sheath temperature must be known in order to ensure it does not equal or exceed the auto-ignition temperature of the flammable product in the hazardous area. Auto-ignition

temperature is the temperature at which combustion can occur without the presence of an open flame or ignition source. To stay well below the auto-ignition temperature of explosive or flammable products, the NFPA® states that a heating device shall not exceed 80% of the product having the lowest auto-ignition temperature in the area in question.

To ensure that products are deemed safe and suitable for use in hazardous areas, independent companies conduct tests and issue certifications. Among these are Underwriters Laboratories (UL®), Factory Mutual Research Corporation (FM®), Canadian Standards Association (CSA®) as well as other international agencies. These agencies test heating cables for electrical, mechanical, and operational reliability and safety.

Abnormal conditions such as overvoltage, controller failure, and high ambient temperature can cause a cable's sheath temperature to rise beyond a safe level. Knowing a cable's maximum sheath temperature when operated in normal and abnormal conditions helps identify the hazardous areas where cable products can be used. A product like self regulating cable that is designed to limit its sheath temperature, even in abnormal circumstances, receives a T-Class rating. T-Class ratings are based on temperature with T-6 being the lowest and T-1 being highest. T-Class ratings help identify the suitability of heating devices for hazardous areas based on the auto-ignition temperature of chemicals in the hazardous area. Sheath temperatures must be calculated on a case-by-case basis for those products that are not capable of limiting sheath temperatures.

Although the following paragraphs detail how to calculate sheath temperatures for normal operation, only authorized factory personnel are certified to provide this information as part of a heating cable design. For self regulating cables, use the T-Class ratings when assisting customers. The calculations shown below are primarily used for constant wattage and mineral insulated cables. **Consult with the heat trace manufacturer if a project arises that requires sheath temperature calculations.**

**Table 10: T-Class Ratings**

T-Class	Maximum Temperature °C	Maximum Temperature °F
T-6	85	185
T-5	100	212
T-4A	120	248
T-4	135	275
T-3C	160	320
T-3B	165	329
T-3A	180	356
T-3	200	392
T-2D	215	419
T-2C	230	446
T-2B	260	500
T-2A	280	536
T2	300	572
T-1	450	842

\*Data obtained from NEC®, 1996 edition

The Institute of Electrical and Electronic Engineers (IEEE®) has prepared a standard, IEEE-515, that details various aspects of heating cable systems. Within the document is the general formula that is used to calculate sheath temperatures for normal conditions. To calculate the sheath temperature of a cable, several variables are required. They are:

- 3.41, conversion from BTU to watts, BTU/W
- Q, Cable wattage for one linear foot, W/hr
- A, Surface area of one linear foot of cable, ft<sup>2</sup>
- U, Heat transfer coefficient, BTU/(hr · ft<sup>2</sup> · °F)
- T<sub>p</sub>, Pipe maintenance temperature

During normal operation, a cable sheath temperature is:

$$T_{sh} = \text{self generating temperature} + \text{pipe maintenance temperature}$$

$$\text{Eq. 5.1} \quad T_{sh} = \frac{3.41 Q}{U * A} + T_p$$

Self generating temperature is the temperature rise of the heating cable beyond the pipe temperature. Remember, for heat transfer to occur, a temperature differential must exist. The U-value in Equation 5.1 is the same value introduced in Chapter 1 but was then known as conductance. In Equation 5.1, the U-value varies depending upon the shape and size of the heating cable and the types of heat transfer aids that may be used. These items all factor into how well heat is dissipated from the heating cable and transferred into the pipe. U-values are application specific and must be determined through repeated experimentation; they are usually not available in publications as off-the-shelf values. Table 11 lists some approximate U-values for various constant watt applications. Actual U-values should be obtained by the heat trace manufacturer for the most accurate results.

**Table 11: Typical U-Values**

Test Condition	U-Value
CW Cable, No Heat Transfer aids	3.3
CW Cable, Aluminum tape	5.0
CW Cable, Heat Transfer Cement	10.0

The following example demonstrates the use of heat transfer aids and its effect on lowering sheath temperatures.

**Example 5.1**

A 12 W/Ft constant wattage cable with braid and an FEP overjacket is maintaining 200°F on a metal pipe at 240V operation. The cable measures 3/8" x 1/4". Calculate the sheath temperature without heat transfer aids and with heat transfer cement in place.

First, calculate the area of one foot of heating cable by finding the perimeter of the cable and multiplying by 12 inches. Divide that total by 144 inches to get square feet. Then calculate the sheath temperature.

$$A(\text{ft}^2) = \frac{(1/8" + 1/8" + \pi * 1/4") * 12"}{144}$$

$$\begin{aligned}
 &= \frac{144''/1ft^2}{(1.035'')*12''} \\
 &= 0.086 ft^2
 \end{aligned}$$

$$\begin{aligned}
 T_{sh} &= \frac{3.41 Q + T_p}{U * A} \\
 &= \frac{(3.41 BTU/W)*(12W/hr)}{(3.26 BTU/hrft^2 F)*(0.086 ft^2)} + 200^{\circ}F \\
 &= 146^{\circ}F + 200^{\circ}F \\
 &= 346^{\circ}F \text{ without heat transfer aids}
 \end{aligned}$$

$$\begin{aligned}
 T_{sh} &= \frac{3.41 Q + T_p}{U * A} \\
 &= \frac{(3.41 BTU/W)*(12W/hr)}{(10.0 BTU/hrft^2 F)*(0.086 ft^2)} + 200^{\circ}F \\
 &= 47.6^{\circ}F + 200^{\circ}F \\
 &= 247.6^{\circ}F \text{ with heat transfer cement}
 \end{aligned}$$

The IEEE-515 also considers events that could drive the sheath temperature above the normal operating range. For example, an increase in voltage by 10% causes an increase in cable wattage by 21%. Also, a warmer ambient temperature reduces  $\Delta T$  and the amount of heat loss. Consequently, any excess heat generated by the heating cable is absorbed by the pipe system and raises the temperature. To ensure the maximum sheath temperature generated by a heating cable under abnormal conditions does not exceed 80% of the auto-ignition temperature, different formulas are used. This is worth repeating: **consult with the cable manufacturer if a project arises that requires sheath temperature calculations, especially for hazardous areas.**

**Approvals.** Obtaining third party approvals is essential for applying products in hazardous areas. UL, FM, and CSA do more than just test sheath temperatures. As noted before, these agencies fully test heating cables and their accessories for suitability of use. Each agency has its own standards by which products are tested, though many of the tests accomplish the same objective: safe products.

While it may seem redundant to have three approval agencies, there is enough difference to warrant all three. FM and CSA test and approve heating cables and components for use in Ordinary and Hazardous areas. FM approval is widely accepted in the United States by US industrial facilities. CSA is the Canadian equivalent of FM and is required for cables being installed in Canada. UL takes a slightly different approach to heating cables.

When UL tests heating cable, it determines whether field work will have to be performed to make the final cable terminations. If no field work is required, as is the case with MI cables, UL issues a UL LISTING assuming the cable passes the appropriate tests. However, if the cable will be terminated in the field, as is the case with self regulating and constant wattage, UL will only issue UL RECOGNIZED approval. UL will only LIST a system when the UL tested terminations have been installed per the manufacturer's instructions. This is one way UL tries to assure that the proper kits are being installed in the field. ***The Bottom Line: make sure cables and accessories from different manufacturers are not interchanged. Otherwise, none of the third party approvals will be in effect.***

The best advice about approvals is to ask these questions.

1. What third party agencies are acceptable by the facility where the cables and accessories are being used?
2. Is the area where the cables and accessories are to be installed Ordinary or Hazardous?
3. If the areas is Hazardous, what Class, Division, and Group approvals are required?
4. Consult the latest product data sheets to identify the cables and accessories that have the Class, Division and Group approvals that are required.

#### Example 5.2

Select a heating cable that meets the following criteria:

Maintenance temperature = 190°F

Minimum ambient temperature = 70°F

Exposure temperature = 190°F

Pipe Size = 1" stainless steel

Insulation = 1" calcium silicate

Voltage = 277V

Location = Hazardous, Class I, Division 2, Groups C and D

Auto-ignition Temperature in Hazardous Area = 394.4°C

From Eq 3.1  $Q = 9.38 \text{ W/Ft}$

Using Chromalox® as an example, SRM/E15-2C is FM approved for Class I, Division 2, Groups B,C, and D.

SRM/E15-2C has an output of 8.6 W/Ft at 190°F with an additional 28% output for use on 277V. The total watt density of SRM/E15-2C on 277V at 190°F is 11.0 W/Ft which is greater than 9.38 W/Ft.

80% of auto-ignition temperature = 315°C, SRM/E15-2C has a T-2D rating which is less than 315°C.

**Use SRM/E15-2C in this application.**

### Summary

- In many industrial facilities, explosive or flammable areas exist and are classified as Hazardous by Class, Division and Group.
- Knowing the sheath temperature for a heating product is an important consideration in assessing whether the heater is suitable for use in a particular hazardous application.
- T-Class ratings are useful for selecting heating products for hazardous areas.
- Heat transfer products like aluminum tape lower sheath temperatures. When sheath temperatures are calculated for hazardous areas, the U-value for no heat transfer aids must be used.
- Several independent companies certify products for use in hazardous areas. To maintain proper approvals, do not interchange different manufacturer's products.

### Problems

1. Using Chromalox® products as an example, which of their cables are suitable for use in Class I, Division 1, Group D applications? Which are suitable for Class I, Division 2, Group C and D applications?
2. If chemical solution "examplene" has an auto-ignition temperature of 222°C, what is the maximum allowable T-Class rating of a heating product applied in this application?
3. A 240V, 12 W/Ft nominally rated constant wattage cable with braid and FEP jacket is maintaining 260°F on a metal pipe at 277V operation. The cable measures 3/8" x 1/4". Calculate the sheath temperature using aluminum tape as a heat transfer aid.
4. Re-design Problem 2 of Chapter 4 for use in Class I, Division 2, Group C and D using a remote control panel and low profile (under the insulation) series kits. Panel design and contents not required for this problem.

## Chapter 6: Miscellaneous, But Important, Topics

Chapters 1-5 covered typical heat trace topics. Occasionally, special designs and heat trace calculations arise that must be addressed. Also, problems may arise in the course of heat trace applications. Chapter 6 discusses miscellaneous, but important, topics such as plastic pipe tracing, thermal equilibrium, installation practices, and trouble shooting.

**Non-metallic Pipe Heat Tracing.** Certain piping applications utilize non-metallic pipes rather than steel or copper because of corrosion or cost savings. Non-metallic pipes such as PVC, HPDE, and FRP have relatively low melting temperatures and may be damaged by excessive heat generated by heat trace products. Consequently, heat trace applications on non-metallic pipes require additional design consideration.

Since non-metallic pipes have low maximum exposure temperatures below 225°F, CW, medium/high temperature SR, and MI cables are not recommended on these pipes. Each of these heating cables is capable of generating sheath temperatures well above 225°F. For example, some medium/high temperature SR cables have T-3 (392°F) and T-2D (419°F) ratings that would soften or melt most non-metallic pipe walls. In contrast to this, low temperature SR cables have low T-Class ratings and are suitable for use on non-metallic pipes. Before applying low temperature SR on plastic pipes, verify that the non-metallic pipe can withstand the T-Class ratings as listed for the SR cables.

Because plastics are poor heat transfer conductors, the heat from low temperature SR cables is not dissipated into the pipe wall as well as on metal pipes. Heat is retained in the heating cable matrix. Since self regulating cable responds to added heat by increasing its resistance, the heating cable lowers its heat output. The net effect is that the heating cable performs less efficiently. In fact, because both the pipe and cable are poor heat transfer materials, the drop in thermal output may be as high as 30%.

Heat transfer aids are used to minimize the effects of applying a plastic sheathed cable onto a plastic pipe. Both aluminum tape and heat transfer cements can be used on plastic pipes. As shown in Chapter 5, heat transfer aids lower sheath temperatures and transfers heat into the pipe where it is needed. However, heat transfer aids **are not** required as long as the cable output is greater than the heat loss of the pipe. Graphs 4 and 5 shown below can be used to illustrate the difference of Chromalox® SRL output on plastic pipes with and without aluminum tape.

Example 6.1

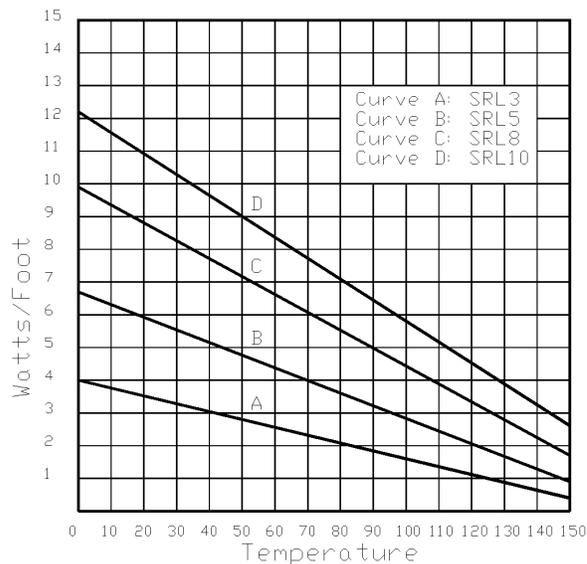
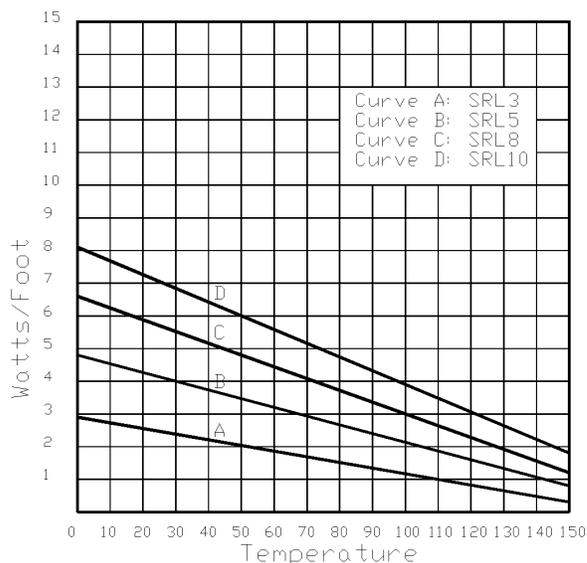
*Select a heating cable wattage for use on a 3" HDPE pipe with 1" fiberglass insulation. The maintenance temperature is 60°F in a 20°F minimum ambient with wind speeds of 30MPH expected.*

*From Eq. 3.1,  $Q = 4.09 \text{ W/Ft}$*

*From Graph 5, SRL8 exceeds  $Q$  with an output of 4.5 W/Ft, no aluminum tape applied.*

*From Graph 6, SRL5 exceeds  $Q$  with an output of 4.4 W/Ft, aluminum tape applied.*

*It is the user's choice as to which cable to use. If longer circuit lengths are required, the user may want to use SRL5 with aluminum tape to get longer circuits on the breakers.*



\*Graph 5 and Graph 6 extrapolated from Chromalox® Design Guide PJ-304-1 to illustrate difference in cable output.

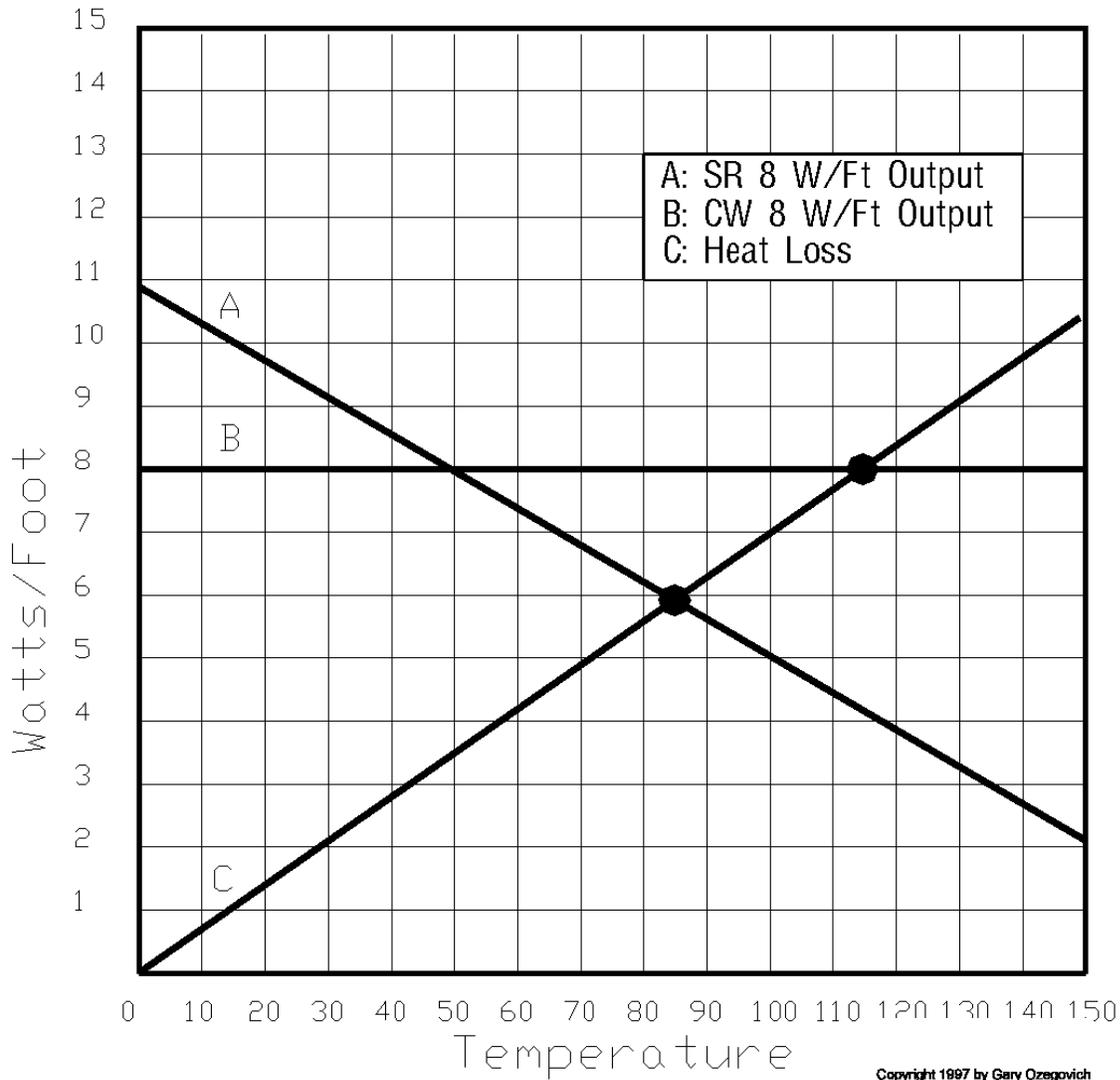
**Graph 5: SRL without Aluminum Tape**

**Graph 6: SRL with Aluminum Tape**

**Thermal Equilibrium.** From time to time, applications arise where a customer is concerned about controller failure and whether the contents of the pipe will be adversely affected. In uncontrolled heat trace systems, excess heat is absorbed by the system and raises the pipe temperature until the heat loss equals the cable output. Chromalox® does not typically recommend this practice because it wastes energy and may overheat the pipe contents over time if the applied heating cable has excess heat capacity. However, the customer may want to know what the thermal equilibrium temperature is – the point at which the heat loss equals the cable output before making a decision on whether to use controls.

Visually, thermal equilibrium is depicted in Illustration 36. Three lines have been drawn to represent heat loss and cable output. The ascending line shows heat loss increasing as the temperature increases. The flat line shows the heat output of constant wattage cable; the output is consistent regardless of temperature. The descending line shows the cable output for self regulating; the output decreases as temperature increases. The point at which the heat loss line intersects with the two cable output curves is the thermal equilibrium temperature for each cable style respectively. As shown in

Illustration 36, self regulating cable has a lower thermal equilibrium temperature than constant wattage cable.



**Illustration 36: Thermal Equilibrium**

The heat loss curve is subject to change as a result of temperatures, pipe sizes, and insulation properties. Consequently, thermal equilibrium will also change. A simple change in the minimum ambient temperature shifts the heat loss curve left or right depending on whether the minimum ambient temperature decreases or increases. Changes in insulation properties affect the slope of the heat loss curve. A steeper curve is the result of less efficient insulation while a more shallow curve means better insulating properties.



SRM/E 10	11.35	0.0284	$Q = 11.35 - 0.0284T_m$
SRM/E 15	17.37	0.0455	$Q = 17.37 - 0.0455T_m$
SRM/E 20	22.53	0.0511	$Q = 22.53 - 0.0511T_m$

Note: For CWM cable, the Y intercept is the cable output wattage and the slope is 0.

Example 6.2

A 2" steel pipe insulated with 2" fiberglass is being maintained at 170°F with a 120V, 15 W/Ft medium/high temperature SR cable. What is the thermal equilibrium temperature on the coldest day of 20°F and the warmest day of 95°F. What is the thermal equilibrium temperature if a 120V, 8 W/Ft CW cable used instead?

Heat loss  $Q = 7.35$  W/Ft

SR output = 10.5 W/Ft @ 170°F using Chromalox® SRM/E 15-1C

Use Equation 6.3 and solve for  $T_m$ .

**Case 1 using 15 W/Ft medium/high temperature SR Cable:**

Coldest Day:

$$T_m = \frac{Y \text{ intercept} + Q_{pt} * T_a}{Q_{pt} + \text{slope}}$$

$$= \frac{17.37 + (0.049)(20)}{0.049 + 0.0455}$$

$$\approx 194 \text{ } ^\circ\text{F}$$

Warmest Day:

$$T_m = \frac{Y \text{ intercept} + Q_{pt} * T_a}{Q_{pt} + \text{slope}}$$

$$= \frac{17.37 + (0.049)(95)}{0.049 + 0.0455}$$

$$\approx 233 \text{ } ^\circ\text{F}$$

**Case 2 using 8 W/Ft CW Cable:**

Coldest Day:

$$T_m = \frac{Y \text{ intercept} + Q_{pt} * T_a}{Q_{pt} + \text{slope}}$$

$$= \frac{8.00 + (0.049)(20)}{0.049 + 0.0}$$

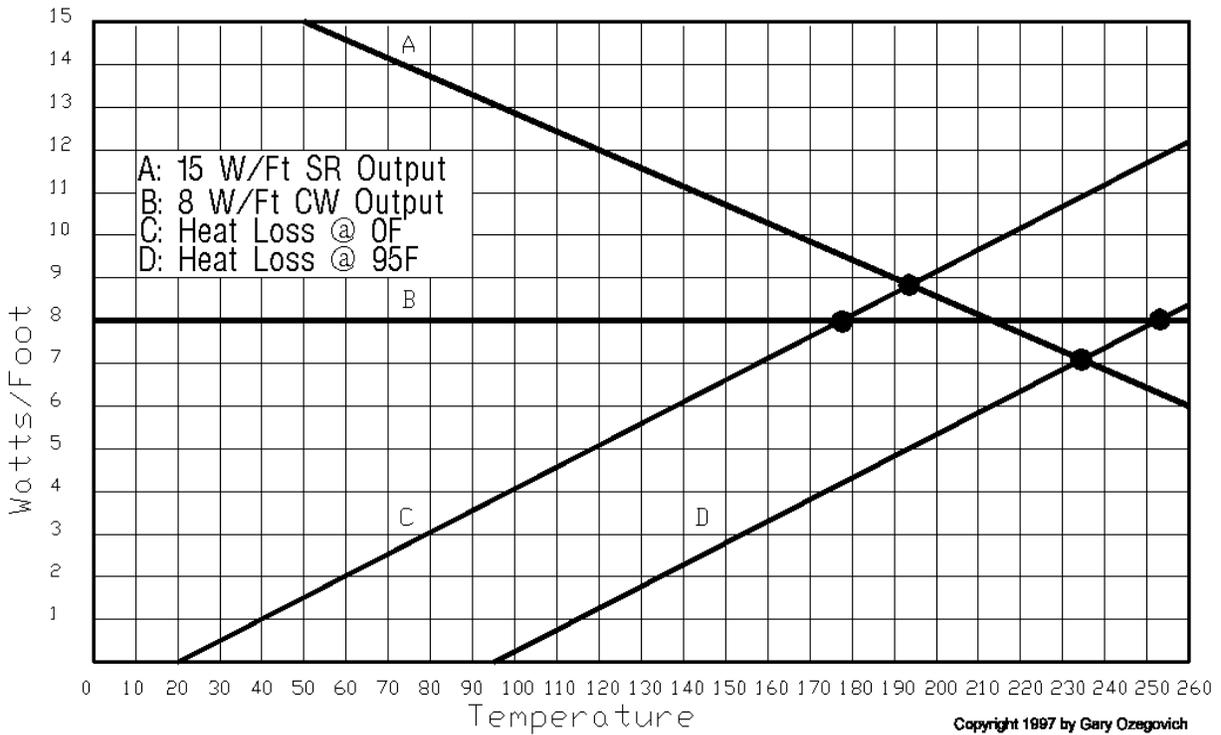
$$\approx 183 \text{ } ^\circ\text{F}$$

Warmest Day:

$$T_m = \frac{Y \text{ intercept} + Q_{pt} * T_a}{Q_{pt} + \text{slope}}$$

$$= \frac{8.00 + (0.049)(95)}{0.049 + 0.0}$$

$$\approx 258 \text{ } ^\circ\text{F}$$



**Illustration 37: Thermal Equilibrium for Example 6.2**

Equation 6.3 makes one basic assumption: the ambient temperature is constant. In reality, ambient temperatures change depending on weather and the amount of sunlight. These changes in ambient temperature affect the amount of heat loss and the overall accuracy of calculating thermal equilibrium temperature. Climate controlled indoor applications are less likely to have wide variations in ambient temperature. As a result, using Equation 6.3 to calculate thermal equilibrium temperature will be much more accurate. Whether the ambient temperature has wide range or not, Equation 6.3 conservatively answers the question of how hot a pipe will get if no controls are used.

**Installation Guidelines.** On occasion, customers request information on how to install heating cables. The most informative literature on installing heating cable is found in Chromalox® Installation and Operation Instructions. These documents thoroughly detail the steps necessary to prepare pipes and vessels, where to apply trace on pipes and how to test the cables to ensure proper operation. In conjunction with the installation instructions, keep in mind the following.

1. Have a training seminar with installation personnel to acquaint them with cables and accessories.
2. Only trace a pipe or vessel after it has been pressure tested. Repair all leaks before installing heating cable.
3. Always start with clean pipes and vessels. Otherwise the application tape will not be able to adhere to the equipment surface. The result is loose fitting cable, poor heat transfer, and overall poor performance of the heat trace system.
4. On single runs of cable, apply to the pipe at 4 o'clock or 8 o'clock position. For multiple runs, space equally between the 4 o'clock and 8 o'clock position.
5. Always trace the outside (larger radius) of elbows. There is more surface area which means higher heat loss.
6. The best method for tracing valves and in-line equipment is to allow a loop of cable, of the proper length for tracing the equipment, to hang by the equipment. Continue tracing the pipe run. After tracing the pipe run, return to the cable loops and trace onto the equipment. Use care to not overlap the cable if the cable is constant wattage or mineral insulated.
7. Attach heating cable to vessels using aluminum tape. On larger tanks that use long circuits, the cable may be supported by affixing pins to the tank wall. Trace the vessel by resting the heating cable on top of the pins and affixing the cable to the vessel with aluminum tape. Then bend the pins over to hold the cable in place. Use caution to prevent pinching the cable with the pins.
8. Avoid spiraling cable if possible. Spiraled installations are more complex and labor intensive. Repairs to pipes are hampered by spiraled cable installations.
9. Be sure to place fiberglass tape on twelve-inch centers maximum when installing heating cable on pipes. Otherwise, the cable may fit too loose and not transfer heat properly. On tight, complex pipes, closer centers may be required.
10. To trace a pipe that runs from above ground to below ground, trace at least 18" below the frost line. Then hairpin back along the pipe and make circuit terminations

above ground. Most heating cable accessories are not rated for submersion in water.

11. For pipe wall sensing controls, place the sensor away from the heating cable, offset by 90 degrees. Placing the sensor too close to the cable may result in poor control.
12. Place ambient sensing controls in the areas that receive the most shade. Otherwise, radiant heating may produce inaccurate control.
13. Be sure that ground braid does not make contact with power or cable bus wires when installing termination accessories.
14. Megohm every cable circuit using a 500VDC megohm device. Any circuits exhibiting ground problems or megohm values below 10Mohm must be repaired or replaced.
15. Record circuit amperages during commission testing. These values will be helpful for testing and maintaining cable circuits over the life of the cable.

### **Trouble Shooting Common Problems and Possible Solutions.**

**WARNING: All trouble shooting and wiring checks shall be performed by qualified electricians or authorized plant personnel. Disconnect ALL power from circuit before servicing or inspecting circuits.**

**Problem: When a circuit breaker is turned ON, the breaker trips instantaneously.**

**Possible Cause:** There is a dead short in the system. To diagnose where the problem is, disconnect the power supply wires from the heating cable at the power connection box. Attach one lead of a megohm device to one bus wire and the other lead to the ground braid.

**Solution #1:** If the megohm device does not register a short circuit, megohm the supply wires. The short probably lies in the power supply to the cable. Repair ground problem in supply wiring.

**Solution #2:** If the short occurs in the heating cable, check these locations in the following order: (1) Power connection box – make sure ground braid is not in contact with bus wires or heater matrix if the cable is self regulating. (2) End seals – pull back just enough thermal insulation to visually inspect the end seal. If the ground braid terminates inside the end seal, remove end seal to determine if ground braid is in contact with bus wires or heater element (matrix). (3) Splice and/or Tee kits – inspect for ground braid contact with bus wires or heater element. Repair as needed. (4) Physical signs of damage to thermal insulation – The cable may have been damaged as a result of an accident with the pipe and cable system.

**Problem: When the circuit breaker is turned ON, the breaker trips within a few seconds.**

**Possible Cause:** Startup current is exceeding the breaker capacity. Use an appropriately sized ammeter to read the current draw when the breaker is first energized. Take the last measurable reading and the length of time the breaker was energized before tripping.

**Solution #1:** If the ampere draw is exceeding the breaker ampacity for absorbing startup current by a narrow margin, try swapping breakers. Thermal breakers are subject to some manufacturing variation.

**Solution #2:** If the ampere draw is exceeding the breaker ampacity for absorbing startup current by a wide margin, the breaker may need to be replaced with a higher rated breaker. Be sure to follow all national and local codes when upgrading circuit ampacities. Supply wires and conduit sizes may also require upgrading.

**Solution #3:** Multiple circuits on one breaker may be drawing too much current. Energize the circuits one at a time to confirm they are drawing the proper amount of current. If necessary, split multiple circuits onto additional breakers.

**Problem: A freeze protection circuit with an ambient sensing thermostat is not energizing when the temperature drops below 40°F.**

**Possible Causes:** Thermostat set point, or, incorrect wiring.

**Solution #1:** Verify the set point of the controller is set correctly. Otherwise, the thermostat will not energize at the proper temperature. Also, check the thermostat to verify that the thermostat is calibrated. Details on calibration are included in the thermostat instruction sheet.

**Solution #2:** The thermostat may be wired incorrectly. The two terminals that should be used are COMMON (COM) and NORMALLY CLOSED (NC). Wired with COM and NC, the heating cable will TURN ON as temperature falls. In some cases, customers have wired thermostats using COMMON and NORMALLY OPEN which causes the heating cable to TURN OFF when the temperature falls.

**Problem: Heating cable is energized but is not drawing full current.**

**Possible Causes:** Wrong voltage, damaged cable, self regulating effect.

**Solution #1:** Check the voltage to be sure the proper voltage is applied. For example, applying 208 volts to a circuit that was supposed to be energized on 240 volts causes a power drop of 25%.

**Solution #2:** On parallel construction cables like self regulating and constant wattage, one of the bus wires may be cut. The cable only produces heat up to the point where the damage has occurred. The result is lower power and lower current draw. To determine if a cable has been cut, check the voltage across the bus wires at the end of the circuit. If there is no voltage, the cable has been cut. If voltage is present, see solutions #1 and #3.

**Solution #3:** If the cable is self regulating, the current draw will be dependent on the temperature of the heating cable and pipe. Cold pipes cause higher current draw. Warm pipes cause lower current draw. If the current is lower than expected on self regulating circuits, measure the pipe temperature and confirm the wattage/current relationship of the heating cable at the higher temperature.

**Problem: Heating cable is drawing proper current but the pipe is not staying warm.**

**Possible Causes:** Improper voltage, wrong cable, wrong design specs, or water contamination in the insulation.

**Solution #1:** This is a side effect to the above problem. Check the voltage to be sure the proper voltage is applied. For example, applying 208 volts to a circuit that was supposed to be energized on 240 volts causes a power drop of 25%. If the power degradation is severe enough, the cable output may not be high enough to offset heat loss.

**Solution #2:** Check the cable catalog number to ensure the proper cable wattage has been applied. If a lower nominal cable wattage was applied, either replace the heating cable with the proper wattage or apply additional insulation until the applied heating cable can properly offset the revised heat loss.

**Solution #3:** Check specifications to ensure proper insulation type and thickness were used based on the heat loss design.

**Solution #4:** Check for moisture infiltration in the insulation. Although heat trace cable is moisture resistant, wet insulation will wick the heat away from the cable. Wet insulation is the leading cause of heat traced pipes not staying warm.

### Summary

- When designing heat trace systems for non-metallic pipes, use only low temperature SR cables. All others may generate temperatures hot enough to damage the pipe.
- Use heat transfer aids such as aluminum tape or heat transfer cement to improve the efficiency of cables on non-metallic pipes.
- Thermal equilibrium is the temperature at which cable output equals the heat loss of the pipe.
- Calculate thermal equilibrium using Equation 6.3 and solving for  $T_m$ .
- Refer to the Chromalox® Installation and Operation Instruction Sheets for comprehensive installation guidelines.

### Problems:

- 1• Select a heating cable for use on a 6" FRP pipe with 2" urethane insulation. The maintenance temperature is 40°F in a -20°F minimum ambient. The customer wants an additional 15% safety factor.
- 2• A customer wants to maintain a 10" steel pipe at 50°F in a 0°F minimum ambient with 25MPH winds. The pipe will be insulated with 1" fiberglass. The customer has a low temperature 120V rated, 8W/Ft SR cable with braid and FEP overjacket in stock and wants to use it for this application. Spiraling is not permitted. Calculate the heat loss and the thermal equilibrium temperature at minimum ambient temperature if the ambient sensing controller fails.

**Appendix: Answers to Problems**

To create a consistent format for problem solutions, all of the solutions presented in this appendix are based on Chromalox® heating cables and accessories and use the latest published information at the time of this printing.

**Chapter 1, Problem 1**

$$\text{Equation 1.6, } Q = \frac{2\pi(k)(\Delta T)(1.1)}{(40.944)\text{LN}(D_o/D_i)} \quad \text{W/Ft hr}$$

First, obtain the values for the variables k, ΔT, Do, and Di.

$$\begin{aligned} k &= (K_m + K_a)/2 \\ &= (0.39 + 0.27)/2 \\ &= 0.33 \text{ BTUin/hrFt}^{\circ}\text{F} \end{aligned}$$

$$\begin{aligned} \Delta T &= T_m - T_a \\ &= 320^{\circ}\text{F} - 70^{\circ}\text{F} \\ &= 250^{\circ}\text{F} \end{aligned}$$

$$\begin{aligned} D_o &= 6.625 \text{ inches of pipe} + 4 \text{ inches of insulation} \\ &= 10.625 \text{ inches} \end{aligned}$$

$$D_i = 6.625 \text{ inches}$$

Next insert these values into Equation 1.6 and solve for Q.

$$\begin{aligned} Q &= \frac{2\pi(0.33)(250)(1.1)}{(40.944)\text{LN}(10.625/6.625)} \quad \text{W/Ft hr} \\ &= \frac{570.199}{19.340} \\ &= \mathbf{29.48 \text{ W/Ft hr}} \end{aligned}$$

Occasionally, the question arises as to how much heat loss occurs across the pipe wall. This exercise demonstrates that the amount of heat loss across a steel pipe wall is insignificant as compared to the heat loss across the insulation. To solve Part 2, use Equation 1.1 to calculate the resistance of the pipe wall as well as the total thermal resistance of the system. The amount of temperature drop across the pipe wall is directly proportional to the percentage of thermal resistance of the pipe wall versus the overall system resistance.

$$\begin{aligned} R(\text{system}) &= R(\text{steel wall}) + R(\text{air}) + R(\text{fiberglass}) \\ &= L/k(\text{steel}) + L/k(\text{air}) + L/k(\text{fiberglass}) \\ &= (0.625/325.3) + (0.07/0.167) + (2/0.33) \\ &= 0.00192 + 0.41916 + 6.06061 \\ &= 6.48169 \end{aligned}$$

$$\begin{aligned} \text{Resistance percentage of steel wall to overall system} &= (0.00192)/(6.48169) \\ &= 0.000296 \end{aligned}$$

The temperature drop across the steel wall is  $250^{\circ}\text{F} * 0.000296$  or  $0.074^{\circ}\text{F}$ .

$$\begin{aligned} \text{The actual pipe wall temperature at the outer surface} &= 320^{\circ}\text{F} - 0.074^{\circ}\text{F} \\ &= \mathbf{319.926^{\circ}\text{F}} \end{aligned}$$

**Chapter 1, Problem 2**

Calculate heat up and heat loss for the system and add the two for the total heat required.

$$\begin{aligned} \text{Heat up, } Q1 &= \frac{MC \Delta T}{3.412} \text{ Watts/hr} \\ &= \frac{[(M_{\text{pipe}})(C_{\text{pipe}}) + (M_{\text{air}})(C_{\text{air}})](\Delta T)}{3.412} \\ &= \frac{[(10.79 \text{ lb})(0.12) + (0.08 \text{ lb/ft}^3)(0.088\text{ft}^3)(0.2377)](50^\circ\text{F})}{3.412} \\ &= 19.0 \text{ Watts/hr} \end{aligned}$$

$$\begin{aligned} \text{Heat loss, } Q2 &= \frac{2\pi(k)(\Delta T)(1.1)}{(40.944)\text{LN}(D_o/D_i)} \text{ Watts/hr} \\ &= \frac{2\pi(0.24)(50)(1.1)}{(40.944)\text{LN}(6.5/4.5)} \text{ Watts/hr} \\ &= 5.51 \text{ Watts/hr} \end{aligned}$$

$$\begin{aligned} QT &= Q1 + Q2 \\ &= 19.0 + 5.51 \text{ Watts/hr} \\ &= \mathbf{24.51 \text{ Watts/hr}} \end{aligned}$$

**Chapter 1, Problem 3**

To solve this problem, calculate the amount of heat in watts required to change the temperature of the pipe and water by the temperature differential of 18°F. Next, calculate the heat loss of the pipe.

$$\begin{aligned} \text{Heat up, } Q1 &= \frac{MC \Delta T}{3.412} \text{ Watts} \\ &= \frac{[(M_{\text{pipe}})(C_{\text{pipe}}) + (M_{\text{water}})(C_{\text{water}})](\Delta T)}{3.412} \\ &= \frac{[(10.79 \text{ lb})(0.12) + (5.5 \text{ lb})(1)](18^\circ\text{F})}{3.412} \\ &= 35.85 \text{ Watts} \end{aligned}$$

$$\begin{aligned} \text{Heat loss, } Q2 &= \frac{2\pi(k)(\Delta T)(1.1)}{(40.944)\text{LN}(D_o/D_i)} \text{ Watts/hr} \\ &= \frac{2\pi(0.24)(18)(1.1)}{(40.944)\text{LN}(6.5/4.5)} \text{ Watts/hr} \\ &= 1.98 \text{ Watts/hr} \end{aligned}$$

Number of hours for pipe and water to fall to 32°F:

$$\begin{aligned} \text{Time} &= \frac{Q1, \text{ Watts}}{Q2, \text{ Watts/hr}} \\ &= \frac{35.85 \text{ Watts}}{1.98 \text{ Watts/hr}} \\ &= \mathbf{18.1 \text{ hours}} \text{ until the pipe and water is cold enough to freeze} \end{aligned}$$

**Chapter 3, Problem 1**Step 1: Calculate heat loss.

$$\begin{aligned} \text{From Equation 3.1, } Q &= (Q_p)(\Delta T)(\%MPH)(K_{\text{mean}})(\%SF) \text{ W/Ft} \\ &= (0.052)(120)(1.00)(1.60)(1.10) \\ &= \mathbf{10.98 \text{ W/Ft}} \end{aligned}$$

$$\begin{aligned} Q_p &= 0.052 \\ \Delta T &= 140^\circ\text{F} - 20^\circ\text{F} = 120^\circ\text{F} \\ \%MPH &= 1.00, \text{ No additional allowance required} \\ K_{\text{mean}} &= 2(0.37 + 0.43) = 1.60, \text{ Table 5} \\ \%SF &= 1.10, \text{ Since no safety factor given, use 10\% standard} \end{aligned}$$

Step 2: Review Ratings to find suitable cable(s)

- From Table 3, the cables that can withstand 140°F maintenance temperature, 215°F exposure temperature and are suitable for 240V operation are **SRM/E, CWM and MI**.

Step 3: Calculate cable length.

- SRM/E Solution:** If SRM/E is used, SRM/E20-2 provides 15 W/Ft @ 140°F. Requires 1 run.  
Cable length required for pipe = Pipe length x number of passes of SRM/E20-2  
= 266 feet x 1 pass = 266feet  
Cable length required for equipment =  $\Sigma (Q \cdot \text{Allowance}) / (\text{SRM/E20-2 Output})$   
=  $10.98 \text{ W} * [(2 \text{ gate valves})(5.0) + (11 \text{ supports})(2.0)] / (15.0 \text{ W/Ft})$   
= 23.4 feet  
Total cable length required ~ **290 feet of SRM/E20-2C @ 15.0 W/Ft output**
- CWM Solution:** If CWM is used, CWM12-2 provides 12 W/Ft @ 140°F. Requires 1 run.  
Cable length required for pipe = Pipe length x number of passes of CWM12-2  
= 266 feet x 1 pass = 266feet  
Cable length required for equipment =  $\Sigma (Q \cdot \text{Allowance}) / (\text{CWM12-2 Output})$   
=  $10.98 \text{ W} * [(2 \text{ gate valves})(5.0) + (11 \text{ supports})(2.0)] / (12.0 \text{ W/Ft})$   
= 29.3 feet  
Total cable length required ~ **296 feet of CWM12-2C @ 12.0 W/Ft output**
- MI Solution:** If MI is used, refer to the design solution.  
Step 1. Use Design D, it is the most common and requires only one power termination location.  
Step 2:  $Q = 10.98$  from equation 3.1.  
Step 3: Length can be closely estimated adding the cable length to the equipment allowances times the number of pieces.  $L = 266 \text{ feet} + [(2 \text{ gate valves} * 5.0) + (11 \text{ supports} * 2.0)] = 298 \text{ feet}$   
Step 4: Voltage is 240VAC.  
Step 5:  $\Omega_1/\text{ft} = (V^2) / (Q * L^2)$   
=  $(240^2) / (10.98 * 298^2)$   
= 0.059  $\Omega/\text{ft}$   
Step 6: From Table 3 select 10S2,  $\Omega_2/\text{ft}$  is 0.05 which is less than the value calculated in step 5.  
Step 7:  $W/\text{Ft} = (V^2) / (\Omega_2/\text{ft} * L^2)$        $W = (V^2) / (\Omega_2/\text{ft} * L)$   
=  $(240^2) / (0.05 * 298^2)$       =  $(240^2) / (0.05 * 298)$   
= 12.97 W/Ft      ~ 3,866 watts  
Step 8:  $I = 3,866 \text{ watts} / 240\text{V}$   
= 16.11 amperes  
Step 9: Seven feet of cold lead is standard and sufficient for the application.  
Step 10: For alloy cables, always use type X hot-to-cold joint.  
Step 11: Cable catalog number is - **D / 10S2 / 298 / 3866 / 240 / 7 / 14 / X**

**Chapter 3, Problem 2**

Since the customer only has a single 20 ampere, 120V breaker available, the wattage is limited to 1920 watts. (1920 watts was found by multiplying 120 volts by 80% of the 20 ampere breaker capacity, or 16 amperes.) This problem must be reverse engineered by limiting the heat loss to less than 1920 watts and selecting an insulation type and thickness. To limit the heat loss, rearrange equation 3.3 and solve for Qt. Then select an insulation thickness having a value less than the calculated Qt. Finally, rework the calculations with the actual values to confirm the solution.

Step 1: Find the surface area of the tank.

$$\begin{aligned} SA &= \text{Cone} + \text{Cylinder wall} + \text{Cylinder top} \\ &= \frac{\pi(D+d)}{2} \sqrt{\frac{(D-d)^2 + h^2}{4}} + \pi DH + \frac{\pi D^2}{4} \\ &= \frac{\pi(8.5+0.25)}{2} \sqrt{\frac{(8.5-0.25)^2 + 6.75^2}{4}} + \pi(8.5)(8.0) + \frac{\pi(8.5)^2}{4} \\ &= 108.7 \text{ ft}^2 + 213.6 \text{ ft}^2 + 56.7 \text{ ft}^2 \\ &= 379.0 \text{ ft}^2 \end{aligned}$$

Step 2: Find the temperature differential.

$$\begin{aligned} \Delta T &= T_m - T_a \\ &= 50^\circ\text{F} \end{aligned}$$

Step 3: Using equation 3.3 and rearranging the values, solve for Qt. Note - 0.9 in denominator for indoor location.

$$\begin{aligned} Q_t &= \frac{Q \text{ watts}}{(\Delta T)(A)(\%MPH)(K_{\text{mean}})(\%SF)(0.9)} \\ &= \frac{1920}{(50)(379)(1.0)(1.0)(1.00)(1.1)(0.9)} \\ &= 0.102 \text{ W/Ft}^{20}\text{F} \end{aligned}$$

Step 4: Using Table 10, 1" of insulation has a Qt of 0.081 which is less than the value calculated in Step 3. Assuming fiberglass insulation is suitable for use in the food processing facility, rework equation 3.3 and insert actual values to calculate true heat loss.

$$\begin{aligned} Q &= (Q_t)(\Delta T)(A)(\%MPH)(K_{\text{mean}})(\%SF)(0.9) \\ &= (0.081)(50)(379)(1.0)(1.12)(1.1)(0.9) \\ &= 1,702 \text{ watts which is less than maximum allowable wattage.} \end{aligned}$$

Step 5: Calculate cable length, using standard 50% coverage guideline.

$$\begin{aligned} \text{Length} &= \left[ (\pi * \text{Centers} / 2) + \% \text{of Coverage} (2H - \text{Centers}) \right] * \frac{\pi D}{\text{Centers}} \\ &= [(3.14 * 1/2) + 0.5(2 * 8 - 1)] * (3.14(8.5)/1) \\ &= 242 \text{ ft.} \end{aligned}$$

Step 6: Determine appropriate cable watt density.

$$\begin{aligned} q &= Q/L \\ &= (1,702 \text{ watts}) / (242 \text{ feet}) \\ &= 7 \text{ W/Ft} \end{aligned}$$

Step 7: Select a cable that can withstand 130°F, is suitable for use on 120VAC and can provide at least 7 W/Ft output at 110°F. Overheating may be a concern; use a self regulating cable. SRM/E 10-1C has an output of 8.0 W/Ft at 110°F.

Step 8: Rework the cable footage since output does not equally match the value found in Step 6.

$$\begin{aligned} L &= Q / (\text{Cable Output}) \\ &= (1,702 \text{ W}) / (8.0 \text{ W/Ft}) \\ &\sim 213 \text{ feet of SRM/E 10-2C} \end{aligned}$$

**Chapter 3, Problem 3**

Step 1: Calculate the surface area to be protected.

$$\begin{aligned} A &= L \times W \\ &= (35)(24) \\ &= 840 \text{ ft}^2 \end{aligned}$$

Step 2: Calculate  $\Delta T$

$$\begin{aligned} \Delta T &= T_m - T_a \\ &= 40^\circ\text{F} - (-20^\circ\text{F}) \\ &= 60^\circ\text{F} \end{aligned}$$

Step 3: Using Equation 1.4, calculate the heat loss, Q.

$$Q = \frac{(k)(A)(\Delta T)(1.1)}{3.412(L)} \text{ watts}$$

The contractor did not supply a k factor and insulation thickness. However, the R-value is known and can be used instead. Refer to equation 1.1 where  $R = L/k$  and rework equation 1.4.

$$\begin{aligned} Q &= \frac{(A)(\Delta T)(1.1)(1.3)}{3.412(R)} \\ &= \frac{(840 \text{ ft}^2)(60^\circ\text{F})(1.1)(1.3)}{3.412 \text{ BTU/W (9 ft}^2\text{Fhr/BTU)}} \\ &= 2,347 \text{ watts/hr} \end{aligned}$$

Step 4: Calculate the cable length. The cable length is a ratio of the area to be protected and the spacing between cables. Close spacing requires more cable but at lower watt density. Wide spacing requires less cable but a higher watt density. Keep the watt density below 8 W/Ft while keeping the spacing between 20" and 36". To begin, use 24" centers then re-design as needed.

$$\begin{aligned} L &= \frac{\text{Total Surface Area, sq ft}}{\text{Distance between cables, feet}} \\ &= \frac{840 \text{ ft}^2}{2 \text{ feet}} \\ &= 420 \text{ feet} \end{aligned}$$

Step 5: Calculate the cable density required.

$$\begin{aligned} q &= Q/L \\ &= 2,347 \text{ Watts}/420 \text{ feet} \\ &= 5.6 \text{ W/Ft} \end{aligned}$$

Step 6: Select a cable. Constant wattage and Mineral insulated cables are generally used since its output does not vary. Since the service voltage is 480VAC with grounded neutral, 277V is available. Using CWM4-2C on 277volts yields a cable output, q, of 5.32 W/Ft.

Step 7: Rework Steps 4 and 5 in reverse order to calculate the actual footage of cable and the spacing required.

$$\begin{aligned} L &= Q/q \\ &= \frac{2,347 \text{ W}}{5.32 \text{ W/Ft}} \\ &\sim 442 \text{ feet} \end{aligned}$$

Spacing = Total surface area/L

$$\begin{aligned} &= \frac{840 \text{ ft}^2}{442 \text{ ft}} \\ &= 1.90 \text{ ft or } 22.8 \text{ inch centers} \end{aligned}$$

**Use 442 feet of CWM 4-2C on 22.8 inch centers. Operate cable on 277VAC.**

**Chapter 3, Problem 4**

Calculate the cable length required.

$$\begin{aligned}
 L &= \text{Gutter perimeter} + \text{overhang} + \text{downspouts} \\
 &= 830 \text{ feet} + 208 \text{ feet of } 24'' \text{ overhang} + 150 \text{ feet downspout} \\
 &= 830 \text{ ft} + 208 \text{ ft} \cdot (3) + 150 \text{ ft} \\
 &= 1,604 \text{ feet of SRF5-2RG}
 \end{aligned}$$

**Chapter 4, Problem 1**

In compliance with 125% NEC® provision, A 20-ampere breaker can support up to 16 amperes. From PDS for SRL, a 20 ampere breaker can support up to 90 feet at 50°F startup temperature.

CWM8-1CT Amperage:

$$\begin{aligned}
 I &= \frac{\text{Total Wattage}}{\text{Voltage}} \\
 &= \frac{(8 \text{ Wt/Ft}) \cdot (1200 \text{ ft})}{120\text{V}} \\
 &= 80 \text{ amperes}
 \end{aligned}$$

$$\begin{aligned}
 \# \text{ of ckts} &= \frac{80 \text{ amperes}}{16 \text{ amperes/ckt}} \\
 &= \mathbf{5 \text{ circuits minimum}}
 \end{aligned}$$

SRL8-1CT Amperage:

$$\begin{aligned}
 \# \text{ of ckts} &= \frac{1200 \text{ feet}}{90 \text{ feet/ckt}} \\
 &\approx \mathbf{14 \text{ circuits minimum}}
 \end{aligned}$$

In this application, it may be advantageous to use CWM8-1CT since there are fewer circuits which translates to lower installation costs for electrical wiring and power connection boxes.

**Chapter 4, Problem 2**

Step 1: Using Eq. 3.1, calculate heat loss.

$$Q = 4.37 \text{ W/Ft}$$

Step 2: Select a cable and quantity. Valve type unknown. Use Gate valve.

Use SRL5-1C, 168 feet

Step 3: Layout flow paths. Refer back to Illustration 30.

Three circuits needed.

Step 4: Calculate current draw and circuit protection for each circuit.

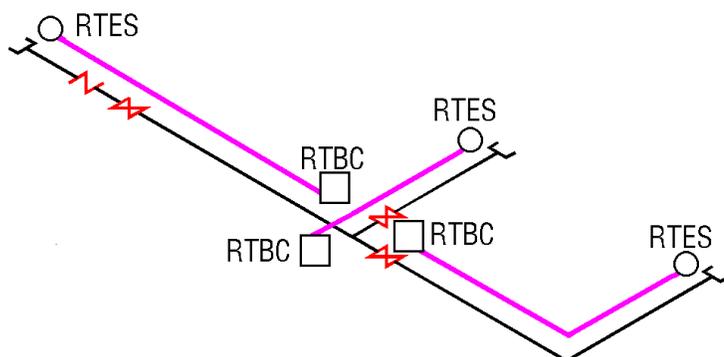
Up to 200 feet of SRL5-1C can be applied to one 20 amp breaker.

$$I = 7.0 \text{ amperes}$$

1 breaker is sufficient

Step 5: Assemble bill of materials.

Catalog Number	Quantity	Where used
SRL5-1C	168 feet	Along pipe wall to maintain pipe temperature
RTBC-1	3 ea.	At beginning of each circuit where V-3 and V-4
RTES-1	3 ea.	At end of circuits
PS-3	3 ea.	At RTBC location to affix boxes to pipe
FT-1	2 rolls	Banded to pipe on 12" centers to affix cable to pipe
CCH-1	3 ea.	At RTBC to apply conduit to box
CL-1	20 ea.	Over insulation on 10 foot centers.



The RTBC enclosures are positioned together to centralize the power wiring and conduit. Most contractors and facility maintenance personnel prefer this method unless specific requirements dictate that controllers be located at a particular point.

**Chapter 4, Problem 3**

The design solution for chapter 3, problem 4 called out for 1,604 feet of SRF5-2RG heating cable. To determine the bill of materials required, calculate the number of electrical circuits, the number of attachment kits, and the termination kits.

Step 1: Number of circuits.

$$\begin{aligned} \# \text{ of ckt} &= \frac{\text{Total footage}}{\text{Feet/ckt}} \\ &= \frac{1604 \text{ total feet}}{185 \text{ feet/ckt}} \\ &\approx 9 \text{ circuits} \end{aligned}$$

Step 2: Number of RCK, roof clip kits

$$\begin{aligned} \# \text{ of RCK} &= \frac{\text{Feet of overhang}}{7 \text{ linear feet/kit}} \\ &= \frac{208 \text{ feet of overhang}}{7 \text{ linear feet/kit}} \\ &\approx 30 \text{ kits} \end{aligned}$$

Step 3: Number of RDK, downspout kits

$$\begin{aligned} \# \text{ of RDK} &= \# \text{ of downspouts} \\ &= 6 \text{ kits} \end{aligned}$$

Step 4: Assemble a bill of materials.

<i>Catalog Number</i>	<i>Quantity</i>	<i>Where used</i>
SRF5-2RG	1604 feet	In eavestroughs, downspouts, and rooftop
RG-PK-1	3 ea.	At beginning of each circuit as needed
JBLT	3 ea.	At beginning of each circuit as needed
RG-EK-1	3 ea.	At end of circuits as needed
RCK-1	30 pks.	On rooftop to affix sinusoidal pattern
RDK-1	6 ea.	At entry point of each downspout

**Chapter 5, Problem 1**

Under special conditions, Chromalox® Mineral Insulated (MI) cable is approved for Class I, Division 1, Group D applications. Consult the factory for details.

SRL and SRM/E are Class I, Division 2, Group C and D approved. When designed by factory authorized personnel, CWM and MI are also Class I, Division 2, Group C and D approved.

**Chapter 5, Problem 2**

$$80\% \text{ of } 222^{\circ}\text{C} = 177.6^{\circ}\text{C}$$

Equipment with T-Class rating T-3B is the highest rating that can be utilized.

**Chapter 5, Problem 3**

Calculate the area of one foot of heating cable by finding the perimeter of the cable and multiplying by 12 inches. Divide that total by 144 inches to get square feet.

$$\begin{aligned} A(\text{ft}^2) &= \frac{(3/16" + 3/16" + \pi 3/8") * 12"}{144"/1\text{ft}^2} \\ &= \frac{(1.553") * 12"}{144"/1\text{ft}^2} \\ &= 0.129 \text{ ft}^2 \end{aligned}$$

CWM 12-2CT on 277V has an output of 16 Watts

$$\begin{aligned}
 T_{sh} &= \frac{3.41 Q}{U * A} + T_p \\
 &= \frac{(3.41 \text{ BTU/W}) * (16.0 \text{ W/hr})}{(5.0 \text{ BTU/hrft}^2 \text{ } ^\circ\text{F}) * (0.086 \text{ ft}^2)} + 260^\circ\text{F} \\
 &= 126.9^\circ\text{F} + 260^\circ\text{F} \\
 &= \mathbf{386.9^\circ\text{F}} \text{ with aluminum tape. This is approaching the maximum exposure temperature and} \\
 &\text{should be reviewed with the factory.}
 \end{aligned}$$

#### Chapter 5, Problem 4

Assemble a bill of materials.

Catalog Number	Quantity	Where used
SRL5-1C	168 feet	Along pipe wall to maintain pipe temperature
JBEP	3 ea.	At beginning of each circuit near V-3 and V-4
RT-JBC-1	3 ea.	Used with JBEP enclosure.
RT-RES	1 pkg	At end of circuits
PS-3	3 ea.	At RTBC location to affix boxes to pipe
FT-1	2 rolls	Banded to pipe on 12" centers to affix cable to pipe
CL-1	20 ea.	Over insulation on 10 foot centers.

In this bill of materials, the RTBC-1 and RTES-1 have been replaced. The JBEP and RT-JBC-1 are now used to make the power connection. One package of RT-RES end seals contains 5 end seals and replaces the 3 RTES-1 kits. Also, the CCH-1 is no longer needed to bring conduit in the box.

#### Chapter 6, Problem 1

$$\begin{aligned}
 \text{From Eq. 3.1 } Q &= (Q_p)(\Delta T)(k)(\%SF) \text{ W/Ft} \\
 &= (0.089)(60)(0.7)(1.15) \\
 &= 4.30 \text{ W/Ft}
 \end{aligned}$$

From Graph 6 in Chapter 5, SRL5 has an output of 5.0 W/Ft with aluminum tape applied.

#### Chapter 6, Problem 2

$$\begin{aligned}
 \text{From Eq. 3.1 } Q &= (Q_p)(\Delta T)(\%MPH)(k) \text{ W/Ft} \\
 &= (0.247)(50)(1.05)(1.0) \\
 &\approx 13.0 \text{ W/Ft}
 \end{aligned}$$

Using SRL8-1CT to offset heat loss requires 2 parallel passes of cable, one at 4 o'clock and one at 8 o'clock.

To determine thermal equilibrium, use equation 6.3 and SRL8-1CT.

Coldest Day:

$$\begin{aligned}
 T_m &= \frac{Y \text{ intercept} + Q_{pt} * T_a}{Q_{pt} + \text{slope}} \\
 &= \frac{10.9 + (0.259)(0)}{0.259 + 0.0586} \\
 &\approx 34^\circ\text{F}
 \end{aligned}$$

Something is wrong here. The cable should have been able to maintain at least 50°F and with an excess of 3 W/Ft, the temperature should have been higher than 50°F, not lower. The error in calculating the thermal equilibrium temperature is that there are two runs of cable, but equation 6.3 is only set up to do thermal equilibrium for one cable pass. Consequently, equation 6.3 must be re-figured using a new formula for equation 6.1 for two runs of cable.

Cable Output for multiple traces:  $Q = \# * (Y \text{ intercept} - \text{slope} * T_m)$ , where # denotes the number of tracers

Solve for  $T_m$  by making Equation 6.2 and the revised Cable Output Equation equivalent.

$$Q_{pt} * (T_m - T_a) = \# * (Y \text{ intercept} - \text{slope} * T_m)$$

$$(Q_{pt} * T_m) - (Q_{pt} * T_a) = (\# * Y \text{ intercept}) - \#(\text{slope} * T_m)$$

$$(Q_{pt} * T_m) + \#(\text{slope} * T_m) = (\# * Y \text{ intercept}) + (Q_{pt} * T_a)$$

$$T_m * (Q_{pt} + \# * (\text{slope})) = (\# * Y \text{ intercept}) + (Q_{pt} * T_a)$$

$$T_m = \frac{(\# * Y \text{ intercept}) + (Q_{pt} * T_a)}{Q_{pt} + \# * (\text{slope})}$$

Inserting Values

$$T_m = \frac{(2 * 10.9) + (0.259 * 0)}{0.259 + (2) * (0.0586)}$$

$$= \frac{21.8}{0.376}$$

$\approx 58^\circ\text{F}$  thermal equilibrium temperature

**NOTES**

**NOTES**

