Application Guide

Electric Heaters

Product Overview

This section of the Application Guide is devoted to electric heaters; their different types, methods of use and general calculations for determining specifications. If you're unable to find or determine which type of Watlow heater will best suit your needs, call your nearest Watlow sales representative. Sales offices are listed on the back cover of this Application Guide.

Heaters

Band and Nozzle Heaters

Led by the high performance MI Band heater, the patented, flexible THINBAND® heater and the standard mica band heater for specialized constructions, Watlow's band and nozzle heaters are ideal for every type of plastic processing equipment.

Sheath materials available include stainless steel with mica insulation, stainless steel with mineral insulation and aluminized or zinc steel with mica insulation.

Performance Capabilities

- Maximum operating temperatures to 760°C (1400°F)
- Typical maximum watt densities from 8.5 W/cm^2 (55 W/in^2) to 35.7 W/cm^2 (230 W/in^2)

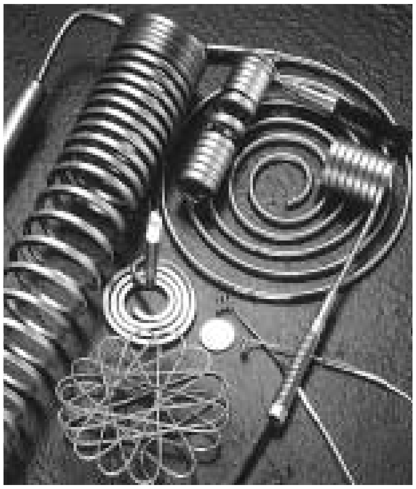
Applications

- Extruders
- Blown film dies
- Injection molding machines
- Other cylinder heating applications

Cable Heaters

The versatile Watlow cable heater can be formed to a variety of shapes as dictated by its many applications. These small diameter, high performance units are fully annealed and readily bent to your desired configuration.

Sheath materials available include Inconel® and stainless steel.



Performance Capabilities

- Typical maximum watt densities to 4.6 W/cm^2 (30 W/in^2)
- Maximum operating temperatures to 650°C (1200°F)

Applications

- Plastic injection molding nozzles
- Semiconductor manufacturing and wafer processing
- Hot metal forming dies and punches
- Sealing and cutting bars
- Restaurant and food processing equipment
- Cast-in heaters
- Laminating and printing presses
- Air heating
- Heating in a vacuum environment
- Textile manufacturing

Inconel® is a registered trademark of the Special Metals Corporation.

Electric Heaters

Product Overview

Continued

Cartridge Heaters

The Watlow FIREROD® heater enters its 50th year of industry leading expertise as the premier choice in swaged cartridge heating. With premium materials and tight manufacturing controls, the FIREROD heater continues to provide superior heat transfer, uniform temperatures and resistance to oxidation and corrosion in demanding applications and high temperatures.

Sheath materials available are Incoloy® and stainless steel.

Performance Capabilities

- Typical maximum watt densities up to 62 W/cm^2 (400 W/in^2)
- Maximum operating temperatures to 760°C (1400°F)

Applications

- Molds
- Dies
- Platens
- Hot plates
- Sealings
- Fluid heating
- Life sciences
- Aerospace
- Semiconductor
- Foodservice equipment

Cast-in Heaters

When Watlow creates a custom-engineered cast-in product, the result is more than just a heater. It's a "heated part" that becomes a functional component of your equipment, designed in the exact shape and size you need. The IFC heated part consists of a Watlow heater element built into custom metal shapes designed specifically for your application.

Sheath materials available are 319 and 356 aluminum, pure aluminum and IFC (stainless, nickel, Inconel®, aluminum, copper and bronze).

Performance Capabilities

- Typical maximum watt densities to 15.5 W/cm^2 (100 W/in^2)
- Maximum operating temperatures to 400°C (752°F) to 760°C (1400°F) depending on material

Applications

- Semiconductor manufacturing
- Foodservice equipment
- Plastics processing
- Medical equipment
- Hot glue melt
- Circulation heating

Incoloy® and Inconel® are registered trademarks of the Special Metals Corporation.

Application Guide

Electric Heaters

Product Overview

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Circulation and Process Heaters

Watlow's circulation heaters are compact heating solutions for fluids such as purified and inert gases, supercritical fluids and liquids like de-ionized water for use in semiconductor and electronics industries as well as for general liquid and gas heating applications. Watlow's industrial process heater lines of immersion, circulation and duct heaters are used to heat a myriad of high and low viscosity fluids ranging from de-ionized and process water, oils, solvents, rinse agents, caustic solutions, etc. to process gases like air, nitrogen, purified and inert gases as well.

Applications

- Oil and gas field equipment
- Refineries & petrochemical plants
- Chemical and industrial gas plants
- HVAC duct heating
- Open tanks and heat treat baths
- Textile drying
- Heat transfer and lube oil systems
- Semiconductor processing equipment
- Precision cleaning equipment
- Power generation systems
- Emissions control systems
- Supercritical fluid heating
- In-line water boilers

Ceramic Fiber Heaters

Ceramic fiber heaters integrate a high temperature iron-chrome-aluminum (ICA) heating element wire with ceramic fiber insulation. Numerous stock, standard and/or custom shapes can be provided, achieving the "heated insulation" concept for your high temperature, non-contact applications. The ceramic fiber insulation isolates the high temperatures inside the heated chamber from the outside. The heaters are low mass, fast heating, with high insulation values and the self-supported heating elements that offer some of the highest temperature heating capabilities within the Watlow family of heater designs.

The sheath material available is molded ceramic fiber.

Performance Capabilities

- Typical maximum watt densities to 1.8 W/cm^2 (11.5 W/in^2)
- Maximum operating temperatures to 1205°C (2200°F)

Applications

- High temperature furnaces
- Metal melting, holding and transfer
- Semiconductor processing
- Glass, ceramic and wire processing
- Analytical instrumentation
- Fluidized beds
- Laboratory and R&D
- Other high temperature process applications

Electric Heaters

Product Overview

Continued

Flexible Heaters

Flexible heaters from Watlow are just what the name implies: thin, bendable and shaped to fit your equipment. You can use your imagination to apply heat to the most complex shapes and geometries conceivable without sacrificing efficiency or dependability.

Sheath materials available include silicone rubber, Kapton®, HT foil and neoprene.

Performance Capabilities

- Typical maximum watt densities from 1.7 W/cm^2 (11 W/in^2) to 17.0 W/cm^2 (110 W/in^2)
- Maximum operating temperatures to 595°C (1100°F)

Applications

- Medical equipment such as blood analyzers, respiratory therapy units and hydrotherapy baths
- Freeze protection for military hardware, aircraft instrumentation and hydraulic equipment
- Battery heating
- Foodservice equipment
- Factory bonding / subassemblies
- Any application requiring a flexible shape or design

Multicell Heaters

The multicell heater from Watlow offers independent zone control for precise temperature uniformity, loose fit design for easy insertion in and removal from the equipment and extreme process temperature capability. The heaters are available with up to eight independently controllable zones and one to three internal thermowells for removable sensors. Custom assemblies are available.

Incoloy® sheath material is available.

Performance Capabilities

- Typical maximum watt densities to 6.2 W/cm^2 (40 W/in^2)
- Maximum operating temperatures to 1230°C (2250°F)

Applications

- Super plastic forming and diffusion bonding
- Hot forging dies
- Heated platens
- Furnace applications
- Superheating of air and other gases
- Fluidized beds for heat treating
- Glass forming, bending and tempering
- Long heater needs (1219 cm (40 foot))
- Soil remediation
- Aluminum processing

Kapton® is a registered trademark of E.I. du Pont de Nemours & Company.

Application Guide

Electric Heaters

Product Overview

Continued

Polymer Heaters

For the latest in heating technology from Watlow, specify a heated plastic part in your next product. Watlow's heated plastic parts combine resistive heating elements with a wide range of thermoplastic compounds to yield a part that is both heater and structure. Watlow utilizes typical injection molding techniques and patented resistive element construction methods to produce heated plastic parts that are durable, safe and cost-effective.

Performance Capabilities

- Typical maximum open watt densities from 0.08 W/cm^2 (0.5 W/in^2) to 0.59 W/cm^2 (3.8 W/in^2)
- Typical maximum immersion watt densities from 0.62 W/cm^2 (4.0 W/in^2) to 9.30 W/cm^2 (60 W/in^2)
- Maximum operating temperatures to 220°C (428°F)

Applications

- Medical
- Analytical
- Aerospace
- Freeze protection
- Battery heating
- Foodservice
- Transportation
- Semiconductor
- Any heated part application requiring a flexible shape

Radiant Heaters

With Watlow's diverse RAYMAX® heater line, we have a solution for almost any application requiring radiant heat. Our capabilities cover a wide range of needs, from contamination-resistant panel heaters to fast-responding quartz tubes to rugged tubular elements and high temperature ceramic panels.

Incoloy® tubular, molded ceramic fiber, quartz tube and stainless steel emitter strip sheath materials are available.

Performance Capabilities

- Typical maximum watt densities from 4.6 W/cm^2 (30 W/in^2) to 7.0 W/cm^2 (45 W/in^2)
- Maximum operating temperatures to 1095°C (2000°F)

Applications

- Thermoforming
- Food warming
- Paint and epoxy curing
- Heat treating
- High temperature furnaces
- Tempering and annealing processes

Alcryn® is a registered trademark of Ferro Corporation.

Santoprene® is a registered trademark of Advanced Elastomer Systems.

Application Guide

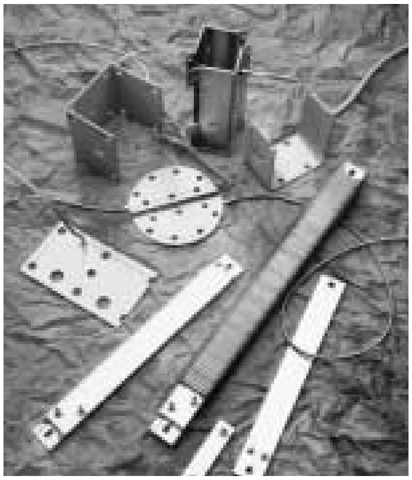
Electric Heaters

Product Overview

Continued

Strip Heaters

Watlow's mica and 375 strip heaters are the versatile solution for a number of applications. They can be bolted or clamped to a solid surface for freeze and moisture protection, food warming and other applications or utilized as a non-contact radiant heater. The 375 finned strip heaters are commonly used for air heating, drying ovens and space heaters.



Performance Capabilities

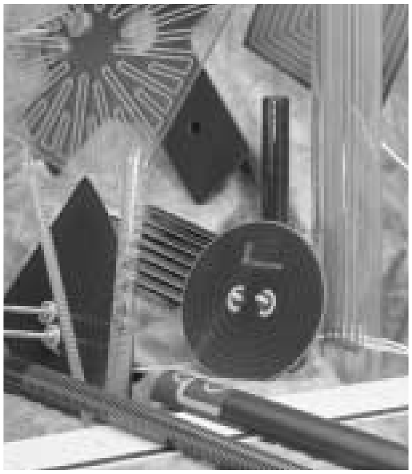
- Typical maximum watt densities from 7.8 W/cm^2 (50 W/in^2) to 15.5 W/cm^2 (100 W/in^2)
- Maximum operating temperatures to 760°C (1400°F)

Applications

- Dies and molds
- Tank and platen heating
- Thermoforming
- Packaging and sealing equipment
- Ovens
- Food warming equipment
- Vulcanizing presses
- Duct, space and air heaters
- Incubators
- Autoclaves
- Freeze and moisture protection

Thick Film Heaters

Watlow layers thick film resistor and dielectric materials on quartz, stainless steel and ceramic substrates to produce high performance industrial heaters. The thick film heaters provide very fast temperature response and uniformity on a low-profile heater. Thick film heaters are ideal for applications where space is limited, where conventional heaters can't be used, when heat output needs vary across the surface, or in ultra-clean or aggressive chemical applications.



430 stainless steel (open air), 430 stainless steel (immersion), aluminum nitride, quartz (open air) and quartz (clamp-on) sheath materials are available.

Performance Capabilities

- Typical maximum watt densities from 3 W/cm^2 (20 W/in^2) to 27 W/cm^2 (175 W/in^2)
- Maximum operating temperatures to 550°C (1022°F)

Applications

- Ultra pure aggressive chemicals
- Large panel processing
- Analytical equipment
- Foodservice equipment
- Packaging sealing equipment
- Life sciences sterilizers and GC/mass spectroscopy
- Semiconductor wafer process equipment
- Plastics hot runners nozzles and manifolds

Application Guide

Electric Heaters

Product Overview

Continued

Tubular and Process Assemblies

Watlow's WATROD tubular heater elements and flat FIREBAR elements are designed primarily for direct immersion in liquids such as water, oils, solvents and process solutions, molten materials as well as air and gases. By generating all the heat within the liquid or process, these heaters are virtually 100 percent energy efficient. These versatile heaters can also be formed and shaped into various geometries for radiant heating and contact surface heating applications. UL® and CSA component recognized elements available.

Applications

- Furnaces and ovens
- Molten salt baths
- Foodservice equipment
- Semiconductor equipment
- Die casting equipment
- Metal melt and holding
- Fluidized beds
- Boilers
- Radiant heating
- Process air heating
- Drying and warming

Application Guide

Electric Heaters

Most electrical heating problems can be readily solved by determining the heat required to do the job. To do this, the heat requirement must be converted to electrical **power** and the most practical heater can then be selected for the job. Whether the problem is heating solids, liquids or gases, the method, or approach, to determining the **power** requirement is the same. **All** heating problems involve the following steps to their solution:

Define the Heating Problem

Calculate Power Requirements

System Start-up and Operating Power Requirement

System Maintenance Power Requirements

Operating Heat Losses

Power Evaluation

Review System Application Factors

Safe/Permissible Watt Densities

Mechanical Considerations

Operating Environment Factors

Safety Factor

Heater Life Requirements

Electrical Lead Considerations

Defining the Problem

Your heating problem must be clearly stated, paying careful attention to defining operating parameters. Gather this application information:

- Minimum start and finish temperatures expected
- Maximum flow rate of material(s) being heated
- Required time for start-up heating and process cycle times
- Weights and dimensions of **both** heated material(s) and containing vessel(s)
- Effects of insulation and its thermal properties
- Electrical requirements—voltage
- Temperature sensing methods and location(s)
- Temperature controller type
- Power controller type
- Electrical limitations

And since the thermal system you're designing may not take into account all the possible or unforeseen heating requirements, don't forget a safety factor. A safety factor increases heater capacity beyond calculated requirements. For details on safety factor, please see "Safety Factor Calculation" under the portion of this section dealing with "Review of Heater Application Factors," on page 20.

Application Guide

Electric Heaters

Power Calculations

Calculations for Required Heat Energy

When performing your own calculations, refer to the Reference Data section (begins on page 127) for values of materials covered by these equations.

The total heat energy (kWH or Btu) required to satisfy the system needs will be either of the two values shown below depending on which calculated result is larger.

A. Heat Required for Start-Up

B. Heat Required to Maintain the Desired Temperature

The power required (kW) will be the heat energy value (kWH) divided by the required start-up or working cycle time. The kW rating of the heater will be the greater of these values plus a safety factor.

The calculation of start-up and operating requirements consist of several distinct parts that are best handled separately. However, a short method can also be used for a quick estimate of heat energy required. Both methods are defined and then evaluated using the following formulas and methods:

Short Method

Start-up watts = A + C + ⅔L + Safety Factor

Operating watts = B + D + L + Safety Factor

Safety Factor is normally 10 percent to 35 percent based on application.

A = Watts required to raise the temperature of material and equipment to the operating point, within the time desired

B = Watts required to raise temperature of the material during the working cycle

Equation for A and B (Absorbed watts-raising temperature)

$$\frac{\text{Weight of material (lbs)} \cdot \text{Specific heat of material (Btu/lb} \cdot \text{°F)} \cdot \text{temperature rise (°F)}}{\text{Start-up or cycle time (hrs)} \cdot 3.412}$$

C = Watts required to melt or vaporize material during start-up period

D = Watts required to melt or vaporize material during working cycle

Equation for C and D (Absorbed watts-melting or vaporizing)

$$\frac{\text{Weight of material (lbs)} \cdot \text{heat of fusion or vaporization (Btu/lb)}}{\text{Start-up or cycle time (hrs)} \cdot 3.412}$$

L = Watts lost from surfaces by:

- Conduction-use equation below
- Radiation-use heat loss curves
- Convection-use heat loss curves

Equation for L (Lost conducted watts)

$$\frac{\text{Thermal conductivity of material or insulation (Btu} \cdot \text{in./ft}^2 \cdot \text{°F} \cdot \text{hr)} \quad \text{Surface area (ft}^2\text{)} \quad \text{Temp. differential to ambient (°F)}}{\text{Thickness of material or insulation (in.)} \cdot 3.412}$$

Electric Heaters

Power Calculations—Conduction and Convection Heating

Equation 1—Absorbed Energy, Heat Required to Raise the Temperature of a Material

Because substances all heat differently, different amounts of heat are required in making a temperature change. The specific heat capacity of a substance is the quantity of heat needed to raise the temperature of a unit quantity of the substance by one degree. Calling the amount of heat added Q, which will cause a change in temperature ΔT to a weight of substance W, at a specific heat of material C_p, then $Q = w \cdot C_p \cdot \Delta T$.

Since all calculations are in watts, an additional conversion of 3.412 Btu = 1 Wh is introduced yielding:

Equation 1

$$Q_A \text{ or } Q_B = \frac{w \cdot C_p \cdot \Delta T}{3.412}$$

Q_A = Heat Required to Raise Temperature of Materials During Heat-Up (Wh)

Q_B = Heat Required to Raise Temperature of Materials Processed in Working Cycle (Wh)

w = Weight of Material (lb)

C_p = Specific Heat of Material (Btu/lb • °F)

ΔT = Temperature Rise of Material ($T_{Final} - T_{Initial}$)(°F)

This equation should be applied to all materials absorbing heat in the application. Heated media, work being processed, vessels, racks, belts, and ventilation air should be included.

Example: How much heat energy is needed to change the temperature of 50 lbs of copper from 10°F to 70°F?

$$Q = w \cdot C_p \cdot \Delta T$$

$$= \frac{(50 \text{ lbs}) \cdot (0.10 \text{ Btu/lb} \cdot {}^\circ\text{F}) \cdot (60^\circ\text{F})}{3.412} = 88 \text{ (Wh)}$$

Equation 2—Heat Required to Melt or Vaporize a Material

In considering adding heat to a substance, it is also necessary to anticipate changes in state that might occur during this heating such as melting and vaporizing. The heat needed to melt a material is known as the **latent heat of fusion** and represented by H_f. Another state change is involved in vaporization and condensation. The **latent heat of vaporization** H_v of the substance is the energy required to change a substance from a liquid to a vapor. This same amount of energy is released as the vapor condenses back to a liquid.

Equation 2

$$Q_C \text{ or } Q_D = \frac{w \cdot H_f}{3.412} \quad \text{OR} \quad \frac{w \cdot H_v}{3.412}$$

Q_C = Heat Required to Melt/Vaporize Materials During Heat-Up (Wh)

Q_D = Heat Required to Melt/Vaporize Materials Processed in Working Cycle (Wh)

w = Weight of Material (lb)

H_f = Latent Heat of Fusion (Btu/lb)

H_v = Latent Heat of Vaporization (Btu/lb)

Example: How much energy is required to melt 50 lbs of lead?

$$Q = w \cdot H_f$$

$$= \frac{(50 \text{ lbs}) \cdot (9.8 \text{ Btu/lb})}{3.412 \text{ Btu/(Wh)}} = 144 \text{ (Wh)}$$

Changing state (melting and vaporizing) is a constant temperature process. The C_p value (from Equation 1) of a material also changes with a change in state. Separate calculations are thus required using Equation 1 for the material below and above the phase change temperature.

Application Guide

Electric Heaters

Power Calculations

Continued

Conduction Heat Losses

Heat transfer by conduction is the contact exchange of heat from one body at a higher temperature to another body at a lower temperature, or between portions of the same body at different temperatures.

Equation 3A—Heat Required to Replace Conduction Losses

$$Q_{L1} = \frac{k \cdot A \cdot \Delta T \cdot t_e}{3.412 \cdot L}$$

Q_{L1} = Conduction Heat Losses (Wh)

k = Thermal Conductivity (Btu • in./ft^2 • °F • hour)

A = Heat Transfer Surface Area (ft^2)

L = Thickness of Material (in.)

ΔT = Temperature Difference Across Material (T_2-T_1) °F

t_e = Exposure Time (hr)

This expression can be used to calculate losses through insulated walls of containers or other plane surfaces **where the temperature of both surfaces can be determined or estimated**. Tabulated values of thermal conductivity are included in the Reference Data section (begins on page 134).

Convection Heat Losses

Convection is a special case of conduction. Convection is defined as the transfer of heat from a high temperature region in a gas or liquid as a result of movement of the masses of the fluid. The Reference Data section (page 127) includes graphs and charts showing natural and forced convection losses under various conditions.

Equation 3B—Convection Losses

$$Q_{L2} = A \cdot F_{SL} \cdot C_F$$

Q_{L2} = Convection Heat Losses (Wh)

A = Surface Area (in^2)

F_{SL} = Vertical Surface Convection Loss Factor (W/in^2) Evaluated at Surface Temperature (See Ref. 9, page 26)

C_F = Surface Orientation Factor

Heated surface faces up horizontally	=	1.29
Vertical	=	1.00
Heated surface faces down horizontally	=	0.63

Radiation Heat Losses

For the purposes of this section, graphs are used to estimate radiation losses. Charts in the Reference Data section (page 127) give emissivity values for various materials. Radiation losses are **not** dependent on orientation of the surface. Emissivity is used to adjust for a material's ability to radiate heat energy.

Equation 3C—Radiation Losses

$$Q_{L3} = A \cdot F_{SL} \cdot e$$

Q_{L3} = Radiation Heat Losses (Wh)

A = Surface Area (in^2)

F_{SL} = Blackbody Radiation Loss Factor at Surface Temperature (W/in^2)

e = Emissivity Correction Factor of Material Surface

Example:

Using Reference 139, page 155, we find that a blackbody radiator (perfect radiator) at 500°F, has heat losses of 2.5 W/in^2.
Polished aluminum, in contrast, (e = 0.09) only has heat losses of 0.22 W/in^2 at the same temperature (2.5 W/in^2 • 0.09 = 0.22 W/in^2).

Electric Heaters

Power Calculations

Continued

Combined Convection and Radiation Heat Losses

Some curves in Reference 139 (page 155) combine both radiation and convection losses. This saves you from having to use both Equations 3B and 3C. If only the convection component is required, then the radiation component must be determined separately and subtracted from the combined curve.

Equation 3D—Combined Convection and Radiation Heat Losses

$Q_{L4} = A \cdot F_{SL}$

Q_{L4} = Surface Heat Losses Combined Convection and Radiation (Wh)

A = Surface Area (in^2)

F_{SL} = Combined Surface Loss Factor at Surface Temperature (W/in^2)

This equation assumes a constant surface temperature.

Total Heat Losses

The total conduction, convection and radiation heat losses are summed together to allow for all losses in the power equations. Depending on the application, heat losses may make up only a small fraction of total power required... or it may be the largest portion of the total. Therefore, **do not** ignore heat losses unless previous experience tells you it's alright to do.

Equation 3E—Total Losses

$Q_L = Q_{L1} + Q_{L2} + Q_{L3}$ If convection and radiation losses are calculated separately. (Surfaces are not uniformly insulated and losses must be calculated separately.)

OR

$Q_L = Q_{L1} + Q_{L4}$ If combined radiation and convection curves are used. (Pipes, ducts, uniformly insulated bodies.)

Equations 4 and 5 Start-Up and Operating Power Required

Both of these equations estimate required energy and convert it to power. Since power (watts) specifies an energy rate, we can use power to select electric heater requirements. Both the start-up power and the operating power must be analyzed before heater selection can take place.

Equation 4—Start-Up Power (Watts)

$$P_s = \left[\frac{Q_A + Q_C}{t_s} + \frac{2}{3}(Q_L)\right] \cdot (1 + S.F.)$$

Q_A = Heat Absorbed by Materials During Heat-Up (Wh)

Q_C = Latent Heat Absorbed During Heat-Up (Wh)

Q_L = Conduction, Convection, Radiation Losses (Wh)

S.F. = Safety Factor

t_s = Start-Up (Heat-Up) Time Required (hr)

During start-up of a system the losses are zero, and rise to 100 percent at process temperature. A good approximation of actual losses is obtained when heat losses (Q_L) are multiplied by ⅔ .

Equation 5—Operating Power (Watts)

$$P_o = \left[\frac{Q_B + Q_D}{t_c} + (Q_L)\right] \cdot (1 + S.F.)$$

Q_B = Heat Absorbed by Processed Materials in Working Cycle (Wh)

Q_D = Latent Heat Absorbed by Materials Heated in Working Cycle (Wh)

Q_L = Conduction, Convection, Radiation Losses (Wh)

S.F. = Safety Factor

t_c = Cycle Time Required (hr)

Application Guide

Electric Heaters

Power Calculations—Radiant Heating

When the primary mode of heat transfer is radiation, we add a step after Equation 5.

Equation 6 is used to calculate the net radiant heat transfer between two bodies. We use this to calculate either the radiant heater temperature required or (if we know the heater temperature, but not the power required) the maximum power which can be transfered to the load.

Equation 6—Radiation Heat Transfer Between Infinite Size Parallel Surfaces

$$\frac{P_R}{A} = \frac{S\ (T_1^4 - T_2^4)\left(\frac{1}{e_f}\right) F}{(144\ in^2/ft^2)\ (3.412\ Btu/Wh)}$$

P_R = Power Absorbed by the Load (watts) - from Equation 4 or 5
A = Area of Heater (in^2) - known or assumed
S = Stephan Boltzman Constant
= $0.1714 \cdot 10^{-8}$ (Btu/Hr. Sq. Ft. $°R^4$)
$T_1(°R)$ = Emitter Temperature (°F + 460)
$T_2(°R)$ = Load Temperature (°F + 460)
e_f = Emissivity Correction Factor - see below
F = Shape Factor (0 to 1.0) - from Reference 139, page 155

e_S = Heater Emissivity (from Material Emissivity Tables)
e_L = Load Emissivity (from Material Emissivity Tables)
D_S = Heater Diameter
D_L = Load Diameter

Emissivity Correction Factor (e_f)

$$e_f = \frac{1}{e_S} + \frac{1}{e_L} - 1$$
Plane Surfaces

$$e_f = \frac{1}{e_S} + \frac{D_S}{D_L}\left(\frac{1}{e_L} - 1\right)$$
Concentric Cylinders Inner Radiating Outward

$$e_f = \frac{1}{e_S} + \left(\frac{D_S}{D_L} \cdot \frac{1}{e_L}\right) - 1$$
Concentric Cylinders Outer Radiating Inward

Power Evaluation

After calculating the start-up and operating power requirements, a comparison must be made and various options evaluated.

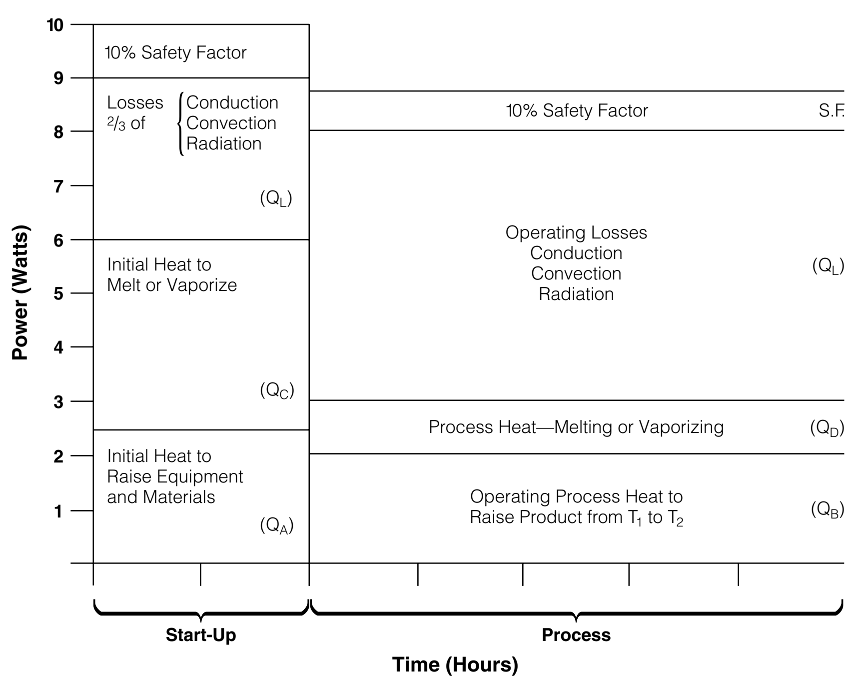
Shown in Reference 1 are the start-up and operating watts displayed in a graphic format to help you see how power requirements add up.

With this graphic aid in mind, the following evaluations are possible:

- Compare start-up watts to operating watts.
- Evaluate effects of lengthening start-up time such that start-up watts equals operating watts (use timer to start system before shift).

Comparison of Start-Up and Operating Power Requirements

Ref. 1



Electric Heaters

Power Evaluation

Continued

- Recognize that more heating capacity exists than is being utilized. (A short start-up time requirement needs more wattage than the process in wattage.)
- Identify where most energy is going and redesign or add insulation to reduce wattage requirements.

Having considered the entire system, a re-evaluation of start-up time, production capacity, and insulating methods should be made.

Review of Heater Application Factors

Safe/Permissible Watt Densities

A heater's watt density rating gives us an indication of how hot a heater will operate. We use this information to establish limits on the application of heaters at various temperatures and under a variety of operating conditions.

The maximum operating watt density is based on applying a heater such that heater life will exceed one year.

In conjunction with desired life, watt density is used to calculate both the required number of heaters and their size.

Silicone Rubber Heater Example: 1000 watts are required for heating a 150°C (300°F) block.
From the silicone rubber heater watt density chart in the flexible heater section of the Watlow Heaters catalog, page 170.

Maximum Watt Density =
16 W/in^2 for wirewound on-off

(2.5 W/in^2) or 38 W/in^2 (6 W/cm^2) for etched foil

This means 63 in^2 of wirewound (five 3 inch • 5 inch heaters) or 27 in^2 of etched foil (two 3 inch • 5 inch heaters) are required.

Mechanical Considerations

Full access must be provided (in the design process) for ease of heater replacement. This is usually done with shrouds or guards over the heaters.

These guards also serve a secondary purpose in that they may minimize convective heat losses from the back of heaters and increase efficiency of the system.

In all applications where the heater must be attached to a surface, it is extremely important to maintain as intimate a contact as possible to aid heat transfer. Heaters mounted on the exterior of a part should have clamping bands or bolts to facilitate this contact. Heaters inserted in holes should have hole fits as tight as possible. Whenever possible, the holes should exit through the opposite side of the material to facilitate removal of the heater.

Operating Environment Factors

- Contaminants are the primary cause of shortened heater life. Decomposed oils and plastics (hydrocarbons in general), conductive pastes used as anti-seize materials, and molten metals and metal vapors can all create situations that affect heater life. Some heater constructions are better sealed against contaminants than others. In analyzing applications, all possible contaminants must be listed in order to be able to fully evaluate the proposed heater.

Example: Heat is required to maintain molten zinc in the passageways of a zinc die casting machine. The possible contaminants for this application are as follows:

a. molten zinc metal
b. zinc vapor
c. hydraulic oils
d. high temperature anti-seize materials
e. moisture, if die cooling is aided by water circulation

All of these factors indicate that a highly sealed heater construction is required.

- The corrosiveness of the materials heated, or the materials that will contact the heater must also be taken into consideration. Even if a heater is completely sealed, the choice of the external sheath material is very important to heater life. A corrosion guide is provided, page 144, and should be consulted in order to avoid using materials that are not compatible with a particular environment.
- Explosive environments generally require that the heater be completely isolated from potentially dangerous areas. This is accomplished by inserting the heater in protective wells and routing the wiring through sealed passage-ways out of the hazardous area. Very close fusing is recommended in these cases to minimize the magnitude of the failure, should it occur.

Application Guide

Electric Heaters

Review of Heater Application Factors
Continued

Safety Factor Calculation

Heaters should always be sized for a higher value than the calculated figure, often referred to as adding in a safety factor.

Generally speaking, the fewer variables and outside influences—the smaller the safety factor.

Here are some general guidelines:

- 10 percent safety factor for large heating systems or when there are very few unknown variables.
- 20 percent safety factor for small to medium heating systems where you are not 100 percent sure you have accurate information.
- 20 to 35 percent for heating systems where you are making many assumptions.

Heater Life Requirements

Temperature

The higher the temperature, the shorter a heater's service life. Mineral insulated heaters using traditional alloys for resistance elements are subject to the life limiting factor of wire oxidation. The winding wire oxidizes at a rate proportional to the element temperature. If the element temperature is known it is possible to project a heater life as shown on the table in Reference 2.

Below are the estimated life expectancies for mineral insulated heater types: FIREROD®, FIREBAR®, Tubular, MI Cable, MI Strip, MI Band.

Ref. 2

Internal Element Temperature °C (°F)	Approximate Life
815 (1500)	3 ½ yrs.
870* (1600)*	1 yr. (2000 hrs.)
925 (1700)	4 mos.
980 (1800)	1 ½ mos.
1040 (1900)	2 wks.
1095 (2000)	1 wk.
1150 (2100)	2 days

* Application charts and operating recommendations use maximum 870°C (1600°F) internal temperature to insure expected heater life greater than one year.

Heaters utilizing lower temperature insulating materials (silicone rubber and mica) have life limiting factors associated with exceeding the temperature limits of the insulation and with thermal cycling. Flexible heaters and mica strip and band heaters must be properly sized and controlled to minimize the temperature swings during thermal cycling of the elements.

Thermal Cycling

Excessive thermal cycling will accelerate heater failure. The worst cycle rate is one which allows full expansion and full contraction of the heater at a high frequency (approximately 30 to 60 seconds on and off).

Prevent excessive cycling by using solid state relays (SSRs) or SCR power controllers. If using SSRs, set the temperature controller's cycle time to one second. If using SCR power controllers (like Watlow's DIN-A-MITE®), be sure to use the variable time base, burst-firing version.

For Immersion Heaters

Use the Corrosion Guide, page 144, and the Selection Guides in the Tubular Elements and Assemblies section of the Watlow Heaters catalog, page 262, to ensure that the sheath material and watt density ratings are compatible with the liquid being heated.

Immersion heaters used in tanks should be mounted horizontally near the tank bottom to maximize convective circulation. However, locate the heater high enough to be above any sludge build-up in the bottom of the tank. Vertical mounting is not recommended.

The entire heated length of the heater should be immersed at all times. Do not locate the heater in a restricted space where free boiling or a steam trap could occur.

Scale build-up on the sheath and sludge on the bottom of the tank must be minimized. If not controlled they will inhibit heat transfer to the liquid and possibly cause overheating and failure.

Extreme caution should be taken not to get silicone lubricant on the heated section of the heater. The silicone will prevent the "wetting" of the sheath by the liquid, act as an insulator, and possibly cause the heater to fail.

Electric Heaters

Review of Heater Application Factors

Continued

Electrical Lead Considerations

General considerations in selecting various lead types are:

- Temperature of lead area
- Contaminants in the lead area
- Flexibility required
- Abrasion resistance required
- Relative cost

Temperatures listed indicate actual physical operating limits of various wire types. Wires are sometimes rated by CSA, UL® and other agencies for operating at much lower temperatures. In this case, the rating agency temperature limit is the maximum level at which this wire has been tested. If agency approvals are required, don't exceed their temperature limits.

Lead Characteristics—Ref. 3

Lead Types	Maximum Lead Area Temperature °C (°F)	Contamination Resistance	Flexibility	Abrasion Resistance	Relative Cost
Lead Protection					
Metal Overbraid	——	Average	Good	Excellent	Moderate
Flexible Conduit	——	Good	Average	Excellent	Moderate
Lead Insulation					
Ceramic Beads	650 (1200)	Poor	Poor	Average	High
Mica-Glass Braid (Silicone or Teflon® Impregnated)	540 (1000)	Poor	Good	Average	High
Glass Braid (Silicone Impregnated)	400 (750)	Poor	Good	Average	Low
Silicone Rubber	260 (500)	Good	Good	Poor	Low
Teflon®	260 (500)	Excellent	Good	Good	Low
PVC	65 (150)	Good	Good	Poor	Low

Teflon® is a registered trademark of E.I. du Pont de Nemours & Company.

UL® is a registered trademark of the Underwriter's Laboratories Inc.

Select Heater

Heater Costs

After calculating wattage required and considering various heater attributes, the scope of possible heater types should be narrowed considerably. Now, several factors not previously examined must be considered before final heater type selection: installation, operation and replacement costs.

Initial Installation Cost

Each heater type has specific installation costs to be considered.

- Machining required— mill, drill, ream
- Materials required— heater, brackets, wiring
- Labor to mount and wire heating elements

Operating Cost

The total system operating cost is a composite of two factors. It is usually best to examine cost on an annual basis:

- Total cost of energy (kW Hours) ($/kWH)

Replacement Cost

The cost of a new heater, lost production time, removal and installation of the new heater must be considered. Generally, these costs are actually much greater than expected. Heater life must be such that replacement can be scheduled and planned during off-peak production times to avoid lost production.

- Removal of existing heater
- Equipment downtime cost
- Material cost— heater, brackets, wiring
- Labor to remove and install heating elements
- Additional purchasing costs
- Scrap products after heater failure and during restart of process
- Frequency of burnouts

Application Guide

Electric Heaters

Select Heater Type, Size and Quantity

Example: A plastic extrusion barrel is operating 40 hours per week. Five band heaters are utilized, 1000 watts each. Energy cost $0.07/kWH. Assume one shift operation or 2080 hours per year Actual power usage is as follows:

Case 1: Shrouded and Uninsulated = 4.06 kW/H

Annual Energy Cost:		
2080 Hours • 4.06 kW/H • $0.07/kWH	=	$591.00
Replacement Cost:		
5 Heaters • $12.00 Each	=	60.00
4 Hours Labor to Install • $20.00/hr	=	80.00
4 Hours Lost Production Time • $50.00/hr	=	200.00
Total/Year	=	$931.00

Case 2: Shrouded and Insulated = 2.38 kW/H

Annual Energy Cost:		
2080 Hours • 2.38 kW/H • $0.07/kWH	=	$346.00
Replacement Cost:		
Same as Case 1	=	340.00
Total/Year	=	$686.00

Here, the cost of operation is much less when insulation is used.

Application Guide

Electric Heaters

Reference Data

Ohm's Law

Ref. 4

Volts

Volts = $\sqrt{\text{Watts x Ohms}}$

Volts = $\frac{\text{Watts}}{\text{Amperes}}$

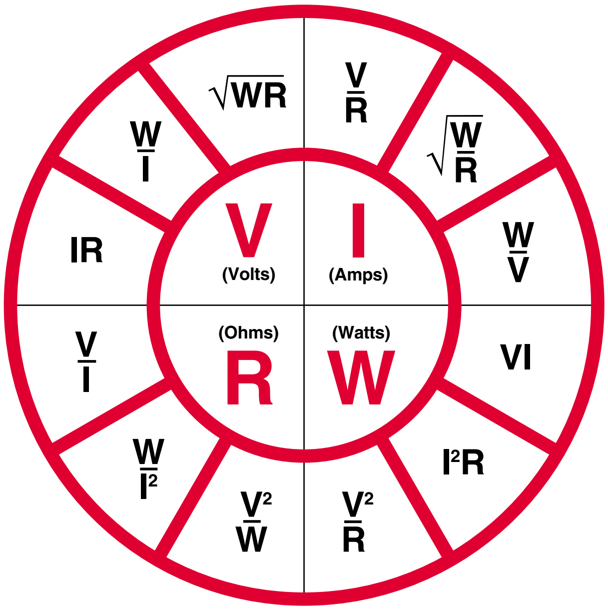
Volts = Amperes x Ohms

Ohms

Ohms = $\frac{\text{Volts}}{\text{Amperes}}$

Ohms = $\frac{\text{Volts}^2}{\text{Watts}}$

Ohms = $\frac{\text{Watts}}{\text{Amperes}^2}$



Amperes

Amperes = $\frac{\text{Volts}}{\text{Ohms}}$

Amperes = $\frac{\text{Watts}}{\text{Volts}}$

Amperes = $\sqrt{\frac{\text{Watts}}{\text{Ohms}}}$

Watts

Watts = $\frac{\text{Volts}^2}{\text{Ohms}}$

Watts = Amperes^2 x Ohms

Watts = Volts x Amperes

Wattage varies directly as ratio of voltages squared

$$W_2 = W_1 \times \left(\frac{V_2}{V_1}\right)^2$$

3 Phase Amperes = $\frac{\text{Total Watts}}{\text{Volts x 1.732}}$

Application Guide

Electric Heaters

Reference Data

Continued

Typical 3-Phase Wiring Diagrams and Equations for Resistive Heaters

Definitions

For Both Wye and Delta (Balanced Loads)

V_P = Phase Voltage

V_L = Line Voltage

I_P = Phase Current

I_L = Line Current

R = $R_1 = R_2 = R_3$ = Resistance of each branch

W = Wattage

Wye and Delta Equivalents

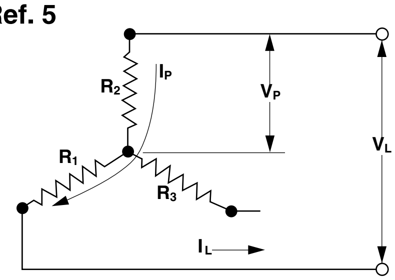
$W_{DELTA} = 3\ W_{WYE}$

$W_{ODELTA} = \frac{2}{3}\ W_{DELTA}$

$W_{OWYE} = \frac{1}{2}\ W_{WYE}$

3-Phase Wye (Balanced Load)

Ref. 5

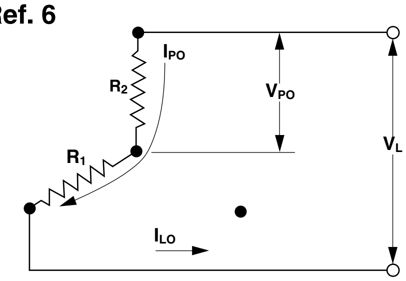


Equations For Wye Only

$I_P = I_L$
$V_P = V_L/1.73$
$W_{WYE} = V_L^2/R = 3(V_P^2)/R$
$W_{WYE} = 1.73\ V_L I_L$

3-Phase Open Wye (No Neutral)

Ref. 6

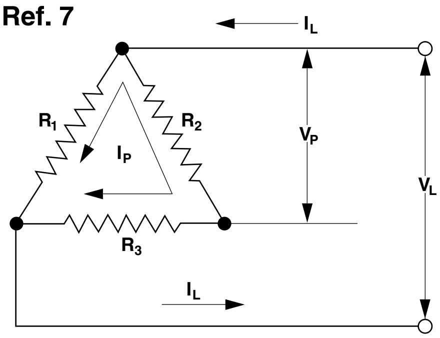


Equations For Open Wye Only
(No Neutral)

$I_{PO} = I_{LO}$
$V_{PO} = V_L/2$
$W_{OWYE} = 1/2\ (V_L^2/R)$
$W_{OWYE} = 2\ (V_{PO}^2/R)$

3-Phase Delta (Balanced Load)

Ref. 7

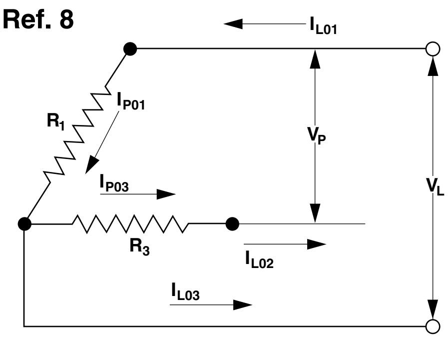


Equations For Delta Only

$I_P = I_L/1.73$
$V_P = V_L$
$W_{DELTA} = 3(V_L^2)/R$
$W_{DELTA} = 1.73\ V_L I_L$

3-Phase Open Delta

Ref. 8



Equations For Open Delta Only

$V_P = V_L$
$I_{P01} = I_{P03} = I_{L02}$
$I_{L03} = 1.73\ I_{P01}$
$W_{0DELTA} = 2\ (V_L^2/R)$

Application Guide

Electric Heaters

Heat Loss Factors and Graphs

Heat Losses at 70°F Ambient

How to use the graph for more accurate calculations

Ref. 9—Convection curve correction factors:

For losses from top surfaces or from horizontal pipes	Multiply convection curve value by 1.29
For side surfaces and vertical pipes	Use convection curve directly
For bottom surfaces	Multiply convection curve value by 0.63

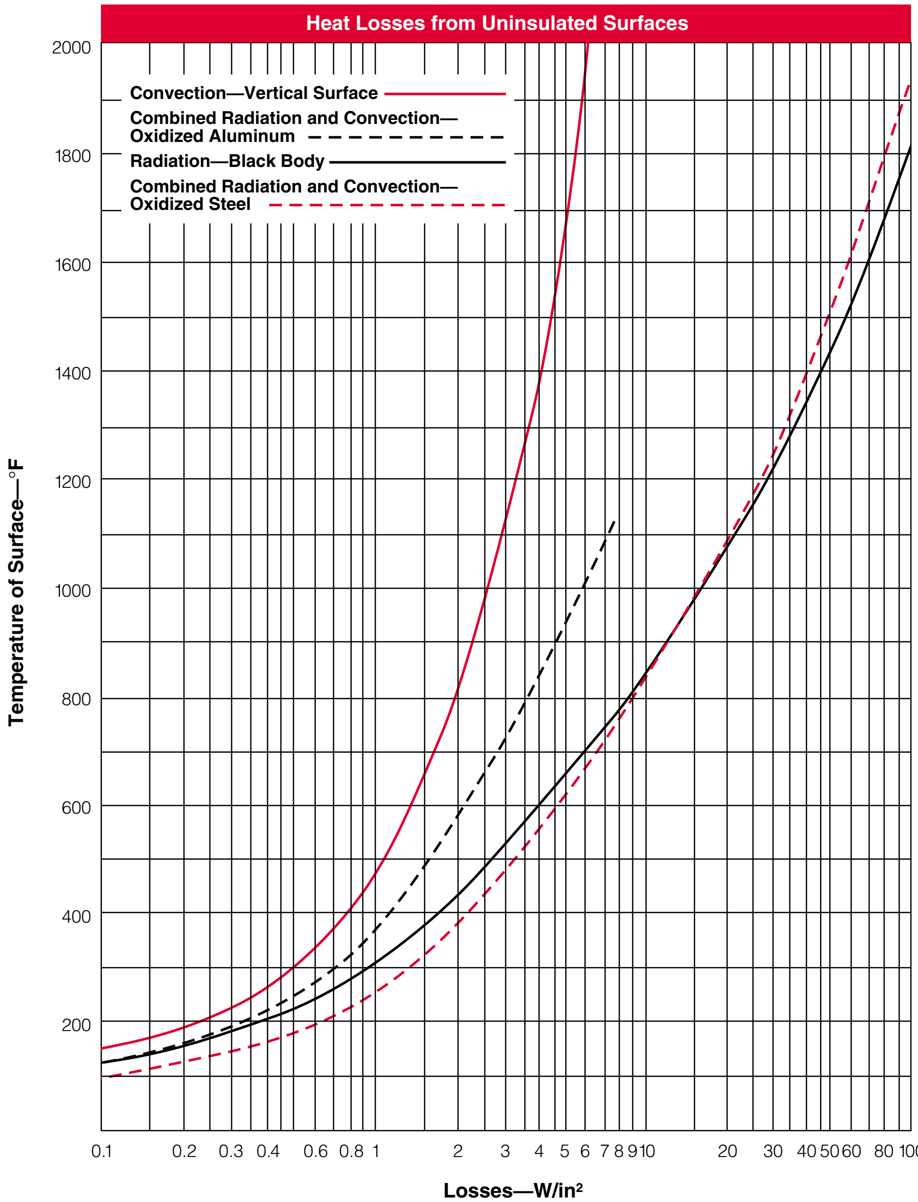
Radiation Curve Correction Factors

The radiation curve shows losses from a perfect blackbody and are not dependent upon position. Commonly used block materials lose less heat by radiation than a blackbody, so correction factors are applied. These corrections are the emissivity (e) values listed to the right:

Total Heat Losses =

Radiation losses (curve value times e)
+ Convection losses (top)
+ Convection losses (sides)
+ Convection losses (bottom)
= Conduction losses
(where applicable)

Ref. 9



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Application Guide

Electric Data

Heat Loss Factors and Graphs

Continued

Helpful Hint: The graphs for losses from **uninsulated** and **insulated** surfaces are hard to read at low temperatures close to ambient. Here are two easy-to-use calculations that are only rule-of-thumb approximations when used within the limits noted.

Rule #1: Losses from an **uninsulated** surface (with an emissivity close to 1.0): (This applies only to temperatures between ambient and about 250°F)

Losses (W/in²) =

$$\frac{\Delta T\ (°F)\ \text{rise above ambient}}{200}$$

Rule #2: Losses from an **insulated** surface: (This insulation is assumed to be one inch thick and have a K-value of about 0.5 Btu-in/hr - ft²-°F. Use only for surfaces less than 800°F.)

Losses (W/in²) =

$$\frac{\Delta T\ (°F)\ \text{rise above ambient}}{950}$$

Incoloy® and Inconel® are registered trademarks of the Special Metals Corporation.

Some Material Emissivities/Metals—Ref. 10

Material	Specific Heat Btu/lb-°F	Emissivity		
		Polished Surface	Medium Oxide	Heavy Oxide
Blackbody			0.75	1.00
Aluminum	0.24	0.09	0.11	0.22
Brass	0.10	0.04	0.35	0.60
Copper	0.10	0.04	0.03	0.65
Incoloy® 800	0.12	0.20	0.60	0.92
Inconel® 600	0.11	0.20	0.60	0.92
Iron, Cast	0.12	—	0.80	0.85
Lead, solid	0.03	—	0.28	—
Magnesium	0.23	—	—	—
Nickel 200	0.11	—	—	—
Nichrome, 80-20	0.11	—	—	—
Solder, 50-50	0.04	—	—	—
Steel				
mild	0.12	0.10	0.75	0.85
stainless 304	0.11	0.17	0.57	0.85
stainless 430	0.11	0.17	0.57	0.85
Tin	0.056	—	—	—
Zinc	0.10	—	0.25	—

Some Material Emissivities/Non-Metals—Ref. 11

Material	Specific Heat Btu/lb-°F	Emissivity
Asbestos	0.25	Most non-metals: 0.90
Asphalt	0.40	
Brickwork	0.22	
Carbon	0.20	
Glass	0.20	
Paper	0.45	
Plastic	0.2-0.5	
Rubber	0.40	
Silicon Carbide	0.20-0.23	
Textiles	—	
Wood, Oak	0.57	

Additional information on emissivities is available from Watlow.

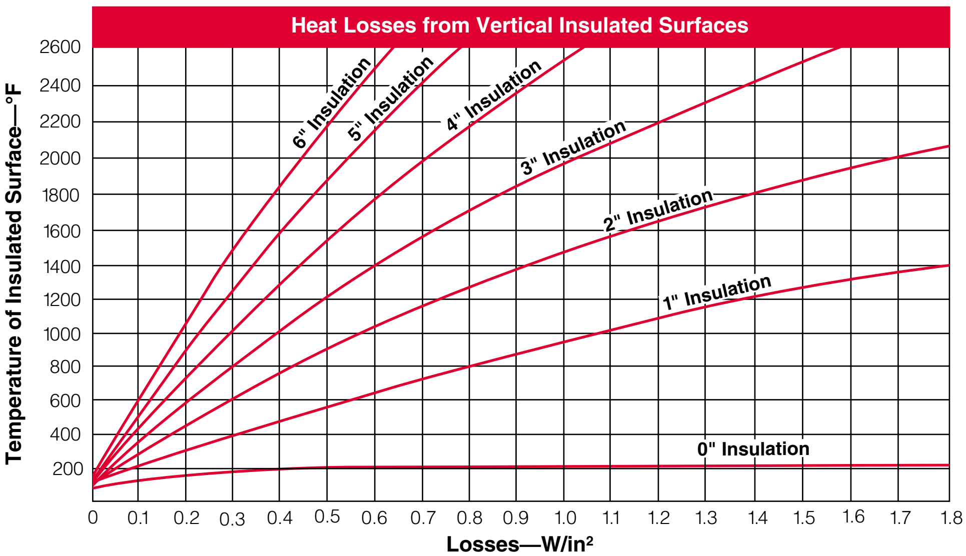
Application Guide

Electric Heaters

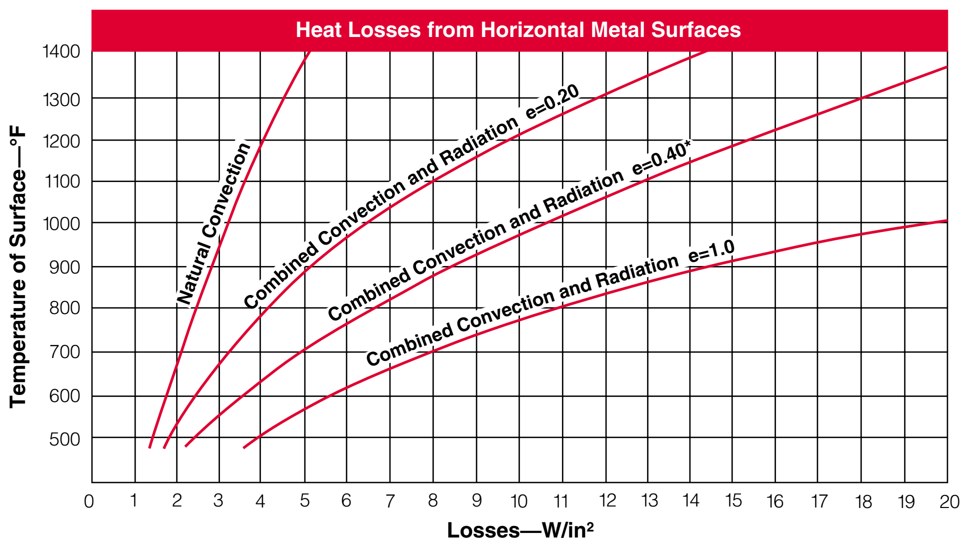
Heat Loss Factors and Graphs
Continued

1. Based upon combined natural convection and radiation losses into 70°F environment.
2. Insulation characteristics
   k = 0.67 @ 200°F
   k = 0.83 @ 1000°F.
3. For molded ceramic fiber products and packed or tightly packed insulation, losses will be lower than values shown.
   For 2 or 3 inches Insulation multiply by 0.84
   For 4 or 5 inches Insulation multiply by 0.81
   For 6 inches Insulation multiply by 0.79

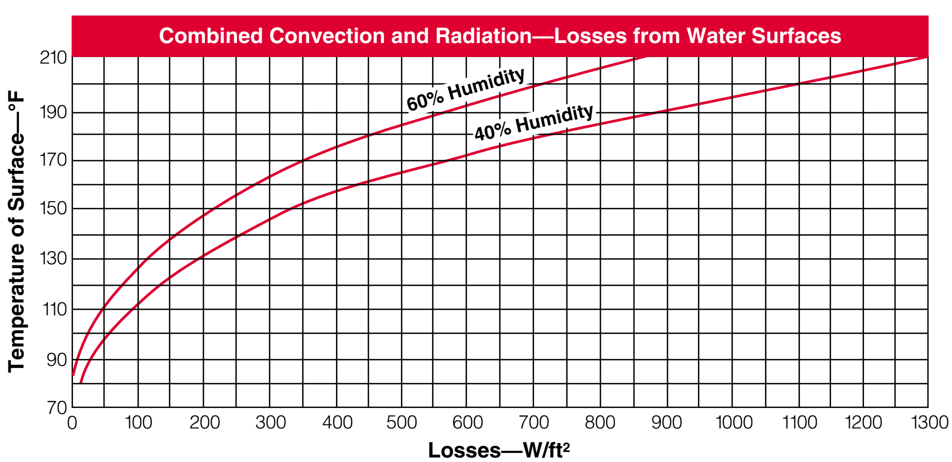
Ref. 12



Ref. 13



Ref. 14

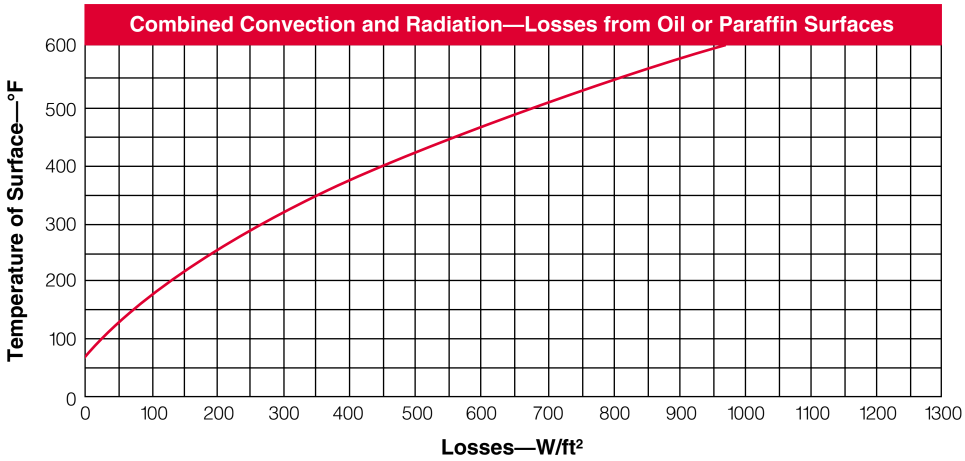


* For losses of molten metal surfaces, use the curve e=0.40.

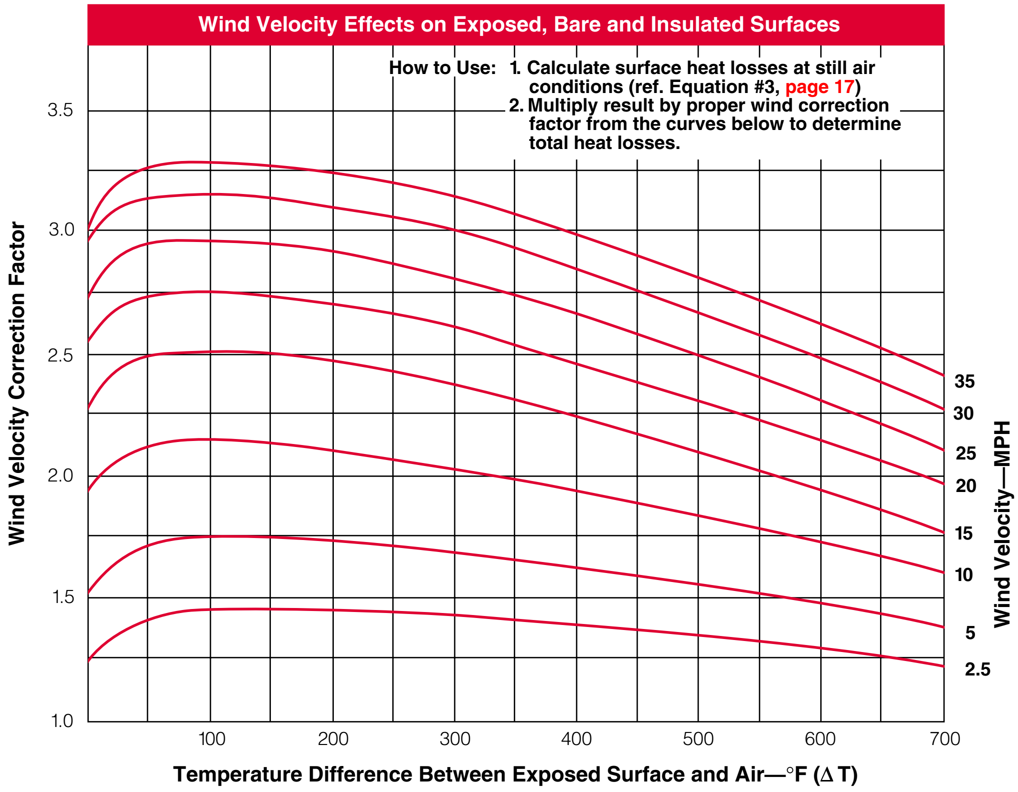
Electric Heaters

Heat Loss Factors and Graphs
Continued

Ref. 15



Ref. 16



Application Guide

Electric Heaters

Quick Estimates of Wattage Requirements

The following tables can be used to make quick estimates of wattage requirements.

For Steel: Use table or metric equation.

$$kW = \frac{\text{Kilograms} \times \text{Temperature Rise (°C)}}{5040 \times \text{Heat-up Time (hrs.)}}$$

$$kW = \frac{\text{Pounds} \times \text{Temperature Rise (°F)}}{20{,}000 \times \text{Heat-up Time (hrs.)}}$$

Kilowatt-Hours to Heat Steel*—Ref. 17

Amount of Steel (lb.)	Temperature Rise °F						
	50°	100°	200°	300°	400°	500°	600°
	Kilowatts to Heat in One Hour						
25	0.06	0.12	0.25	.37	0.50	0.65	0.75
50	0.12	0.25	0.50	.75	1.00	1.25	1.50
100	0.25	0.50	1.00	1.50	2.00	2.50	3.00
150	0.37	0.75	1.50	2.25	3.00	3.75	4.50
200	0.50	1.00	2.00	3.00	4.00	5.00	6.00
250	0.65	1.25	2.50	3.75	5.00	6.25	7.50
300	0.75	1.50	3.00	4.50	6.00	7.50	9.00
400	1.00	2.00	4.00	6.00	8.00	10.00	12.00
500	1.25	2.50	5.00	7.50	10.00	12.50	15.00
600	1.50	3.00	6.00	9.00	12.00	15.00	18.00
700	1.75	3.50	7.00	10.50	14.00	17.50	21.00
800	2.00	4.00	8.00	12.00	16.00	20.00	24.00
900	2.25	4.50	9.00	13.50	18.00	22.50	27.00
1000	2.50	5.00	10.00	15.00	20.00	25.00	30.00

* Read across in table from nearest amount in pounds of steel to desired temperature rise column and note kilowatts to heat in one hour.

Includes a 40 percent safety factor to compensate for high heat losses and/or low power voltage.

For Oil:

Use equation or table.

$$kW = \frac{\text{Gallons} \times \text{Temperature Rise (°F)}}{800 \times \text{Heat-up time (hrs.)}}$$

OR

$$kW = \frac{\text{Liters} \times \text{Temperature Rise (°C)}}{1680 \times \text{Heat-up time (hrs.)}}$$

1 cu. ft. = 7.49 gallons

Kilowatt-Hours to Heat Oil*—Ref. 18

Amount of Oil		Temperature Rise °F					
Cubic Feet	Gallons	50°	100°	200°	300°	400°	500°
0.5	3.74	0.3	0.5	1	2	2	3
1.0	7.48	0.5	1.0	2	3	4	6
2.0	14.96	1.0	1.0	2	4	6	11
3.0	22.25	2.0	3.0	6	9	12	16
4.0	29.9	2.0	4.0	8	12	16	22
5.0	37.4	3.0	4.0	9	15	20	25
10.0	74.8	5.0	9.0	18	29	40	52
15.0	112.5	7.0	14.0	28	44	60	77
20.0	149.6	9.0	18.0	37	58	80	102
25.0	187	11.0	22.0	46	72	100	127
30.0	222.5	13.0	27.0	56	86	120	151
35.0	252	16.0	31.0	65	100	139	176
40.0	299	18.0	36.0	74	115	158	201
45.0	336.5	20.0	40.0	84	129	178	226
50.0	374	22.0	45.0	93	144	197	252
55.0	412	25.0	49.0	102	158	217	276
60.0	449	27.0	54.0	112	172	236	302
65.0	486	29.0	58.0	121	186	255	326
70.0	524	32.0	62.0	130	200	275	350
75.0	562	34.0	67.0	140	215	294	375

* Read across in table from nearest amount in gallons of liquids to desired temperature rise column and note kilowatts to heat in one hour.

Add 5 percent for uninsulated tanks.

Application Guide

Electric Heaters

Quick Estimates of Wattage Requirements

Continued

Kilowatt-Hours to Heat Water*—Ref. 19

Amount of Liquid		Temperature Rise °F						
ft3	Gallons	20°	40°	60°	80°	100°	120°	140°
		Kilowatts to Heat in One Hour						
0.66	5	0.3	0.5	0.8	1.1	1.3	1.6	1.9
1.3	10	0.5	1.1	1.6	2.1	2.7	3.2	3.7
2.0	13	0.8	1.6	2.4	3.2	4.0	4.8	5.6
2.7	20	1.1	2.2	3.2	4.3	5.3	6.4	7.5
3.3	25	1.3	2.7	4.0	5.3	6.7	8.0	9.3
4.0	30	1.6	3.2	4.8	6.4	8.0	9.6	12.0
5.3	40	2.1	4.0	6.4	8.5	11.0	13.0	15.0
6.7	50	2.7	5.4	8.0	10.7	13.0	16.0	19.0
8.0	60	3.3	6.4	9.6	12.8	16.0	19.0	22.0
9.4	70	3.7	7.5	11.2	15.0	19.0	22.0	26.0
10.7	80	4.3	8.5	13.0	17.0	21.0	26.0	30.0
12.0	90	5.0	10.0	14.5	19.0	24.0	29.0	34.0
13.4	100	5.5	11.0	16.0	21.0	27.0	32.0	37.0
16.7	125	7.0	13.0	20.0	27.0	33.0	40.0	47.0
20.0	150	8.0	16.0	24.0	32.0	40.0	48.0	56.0
23.4	175	9.0	18.0	28.0	37.0	47.0	56.0	65.0
26.7	200	11.0	21.0	32.0	43.0	53.0	64.0	75.0
33.7	250	13.0	27.0	40.0	53.0	67.0	80.0	93.0
40.0	300	16.0	32.0	47.0	64.0	80.0	96.0	112.0
53.4	400	21.0	43.0	64.0	85.0	107.0	128.0	149.0
66.8	500	27.0	53.0	80.0	107.0	133.0	160.0	187.0

* Read across in table from nearest amount in gallons of liquid to desired temperature rise column and note kilowatts to heat in one hour.

For Heating Flowing Water:

kW = GPM x Temperature Rise (°F) x 0.16

OR

kW = Liters/min. x Temperature Rise (°C) x 0.076

For Heating Water in Tanks: Use equation or table.

$$\text{kW} = \frac{\text{Gallons x Temperature Rise (°F)}}{\text{375 x Heat-up Time (hrs)}}$$

OR

$$\text{kW} = \frac{\text{Liters x Temperature Rise (°C)}}{\text{790 x Heat-up Time (hrs)}}$$

1 cu. ft. = 7.49 gallons

Kilowatt-Hours to Superheat Steam Ref. 20

1. Plot points on lines P, Q and S.

   P represents the inlet temperature (and saturation pressure) of the system.

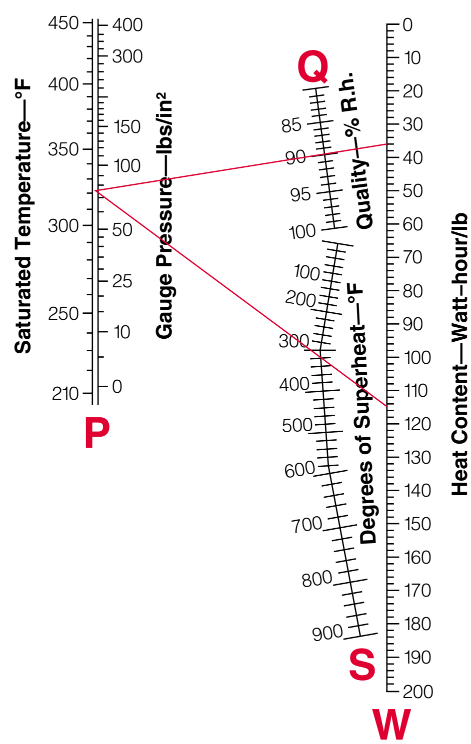
   Q represents the liquid content of the water vapor.

   S indicates the outlet temperature minus the saturated temperature.

   W indicates the heat content of the water vapor.
2. Draw a straight line from P through Q to W. Read W_1.
3. Draw a straight line from P through S to W. Read W_2.
4. Required watts = Weight (lbs.) of steam/hour x (W_2-W_1)

Watt density is critical. Review temperature and velocity prior to heater selection.

Reference is 80 percent quality at 20 psig.



Electric Heaters

Quick Estimates of Wattage Requirements

Continued

Kilowatt-Hours to Heat Air—Ref. 21

Amt. of Air CFM	Temperature Rise °F										
	50°	100°	150°	200°	250°	300°	350°	400°	450°	500°	600°
100	1.7	3.3	5.0	6.7	8.3	10.0	11.7	13.3	15.0	16.7	20.0
200	3.3	6.7	10.0	13.3	16.7	20.0	23.3	26.7	30.0	33.3	40.0
300	5.0	10.0	15.0	20.0	25.0	30.0	35.0	40.0	45.0	50.0	60.0
400	6.7	13.3	20.0	26.7	33.3	40.0	46.7	53.3	60.0	66.7	80.0
500	8.3	16.7	25.0	33.3	41.7	50.0	58.3	66.7	75.0	83.3	100.0
600	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0	120.0
700	11.7	23.3	35.0	46.7	58.3	70.0	81.7	93.3	105.0	116.7	140.0
800	13.3	26.7	40.0	53.3	66.7	80.0	93.3	106.7	120.0	133.3	160.0
900	15.0	30.0	45.0	60.0	75.0	90.0	105.0	120.0	135.0	150.0	180.0
1000	16.7	33.3	50.0	66.7	83.3	100.0	116.7	133.3	150.0	166.7	200.0
1100	18.3	36.7	55.0	73.3	91.7	110.0	128.3	146.7	165.0	183.3	220.0
1200	20.0	40.0	60.0	80.0	100.0	120.0	140.0	160.0	180.0	200.0	240.0

Use the maximum anticipated airflow. This equation assumes insulated duct (negligible heat loss). 70°F inlet air and 14.7 psia.

For Air:

Use equation or table.

$$kW = \frac{\text{CFM* x Temperature Rise (°F)}}{3000}$$

OR

$$kW = \frac{\text{Cubic Meters/Min* x Temperature Rise (°C)}}{47}$$

For Compressed Air:

$$kW = \frac{\text{CFM** x Density** x Temperature Rise (°F)}}{228}$$

OR

$$kW = \frac{\text{Cubic Meters/Min** x Temperature Rise (°C) x Density (kg/m}^3\text{)**}}{57.5}$$

*Measured at normal temperature and pressure.

**Measured at heater system inlet temperature and pressure.