Hitco

Application Guide

CE APPROVED

Redefining Heating Solutions Worldwide ...

Corporate Office
HITCO ELECTRICALS PVT. LTD.
54/C-3, Rama Road Indl. Area, New Delhi-110015
Ph.: 91-11-41061011 (4Lines) Fax: 91-11-41061015
Mobile: 09310008907, E-mail: sales@hitcoelectricals.com
Visit us at www.hitcoelectricals.com

Application Guide

Introduction

This Application guide is to assist you in understanding the principles of electric thermal systems and components as they apply to various heating tasks. Its purpose is to give you theory, general calculations and engineering data along with examples for solving heating problems. This application guide is not a how-to manual or a substitute for specific information related to complex and/or critical applications. Hitco engineers are available to provide you detailed information on engineering approaches not included in this guide.

When designing any thermal system, caution must always be exercised to comply with safety requirements, local and/or national electrical codes, agency standards, consideration for use toxic or explosive environments and sound engineering practices. Integrity and suitability of any thermal system design/specification is ultimately the responsibility of those selecting and approving system components.

This application guide is organized into sections dealing with the basic facets of an electric thermal system: the electric heaters. Information about wiring practices along with references data and examples are also provided. As always Hitco stands ready to provide you advice or engineering expertise to design and produce components to meet your electric heating requirements.

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 Factor

Safe/Permissible Watt densities

Mechanical Consuderations

Operating Environment Factors

Safety Factor

Heater Life Requirement

Electrical Lead Consideration

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 requirement-voltage
- Temperature sensing methods and location9s)
- Temperature controller type
- Power controller type
- Electrical limitations

And since the thermal system you are designing may not take into account all the possible or unforseen 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."

Hitco

Application Guide

Electric Heaters

Power Calculations

Calculations for Required Heat Energy

When performing your own calculation, refer to the Reference Data section 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 consists of several distinct parts that are best handled seperately. However, a short method can also be used for a quick estimate of heat energy required. Both methods are defining and then evaluated using the following formulas and methods:

Short Method

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

Operating Watt = 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)

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

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)

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

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)

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

Hitco

Application Guide

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 T to a weight of substance W, at a specific heat of material Cp, then

Q = W Cp T.

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

Equation 1

$$Q_A \text{ or } Q_B = \frac{W \bullet Cp \bullet T}{3.412}$$

Q_A = Heat Required to Raise Temperature of Material During Heat-Up (Wh)
Q_B = Heat Required to Raise Temperature of Material Processed in Working Cycle (Wh)
w = Weight of Material (lb)
Cp = Specific Heat of Material (Btu/lb * oF)
T = Temperature Rise of Material (TFinal - TInitial)(oF)

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 10oF to 70°F?

$$Q = W \quad Cp \quad \Delta T.$$

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

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 Hf. Another state change is involved in vaporization and condensation. The **latent heat of vaporization** Hv 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

$$Q_C \text{ or } Q_D = \frac{W \quad Hf}{3.412} \quad \text{OR} \quad \frac{W \quad Hv}{3.412}$$

QC = Heat Required to Melt/Vaporize Materials During Heat-Up (Wh)
QD = Heat Required to Melt/Vaporize Materials Processed in Working Cycle (Wh)
w = Weight of Material (lb)
Hf = Latent Heat of Fusion (Btu/lb)
Hv = Latent Heat of Vaporization (Btu/lb)

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

$$Q = W \quad Hf$$

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

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

Application Guide
Electric Heaters

Equation 3A - Heat Required to Replace Conduction Losses

$$Q_{L}1 = \frac{k \quad A \quad \Delta T \quad te}{3.412 \quad L}$$

$Q_{L}1$ = Conduction eat losses (Wh)
k = Thermal Conductivity
(Btu in./ft^2 °F hour)
A = Heat Transfer Surface Area (ft^2)
L = Thickness of Material (in.)
T = Temperature Difference Across Material
(T_2 - T_1) °F
te = Exposure Time (hr)

This expression can be used to calculate losses through insulated walls of containers or other plain surfaces **where the temperature of both surfaces can be determined or estimated.** Tabulated values of thermal conductivity are included in the reference Data Section

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 includes graphs and charts showing natural and forced convection losses under various conditions.

Equation 3B Convection Losses

Q_{l2} = A F_{SL} 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
C_F = Surface Orientation Factor

Heated surfaces 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 give emissivity values for various materials. Radiation losses are **not** dependent on orientation of the surface. Emmisivity is used to adjust for a material's ability to radiate heat energy.

Equation 3C --- Radiation Losses

Q_{L3} = A F_{SL} 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 ,we find that a blackbody radiator (perfect radiator) at 500°F, has heat losses of 2.5 W/in^2.
Polished aluminum, a contrast (e=0.09) only has heat loss of 0.22 W/in2 at the same temperature (2.5 W/in2 * 0.09 = 0.22 W/in^2).

Hitco

Application Guide

Electric Heaters

Power Calculations

Combined Convection and Radiation Heat Losses

Some curves combines 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 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. Herefore, **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, duct, uniformly insulated bodies.)

Equation 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)

$$P_S = \left[\frac{Q_A + Q_C}{t_S}\right] + 2\,(Q_L) \quad (1 + S.F.)$$

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 processes temperature. A good approximation of actual losses is obtained when heat losses (QL) are multiplied by 2/3.

Equation 5 - Operating Power (Watts)

$$P_O = \left[\frac{Q_B + Q_D}{t_C}\right] + 2\,(Q_L) \quad (1 + S.F.)$$

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)

Hitco

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. W 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 transferred 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 (in2) known or assumed

S = Stephan Boltzman Constant

= $0.1714\ \ 10^{-8}$ (Btu/Hr. Sq. Ft. $°R^4$)

$T_1(°R)$ = Emitter Temperature (°F + 460)

$T_2(°R)$ = Load Temperature (°F + 460)

Ef = Emissivity Correction Factor see below

F = shape Factor (o to 1.0)

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 (ef)

$$e_f = \frac{1}{e_L} + \frac{1}{e_L} - 1$$ 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

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

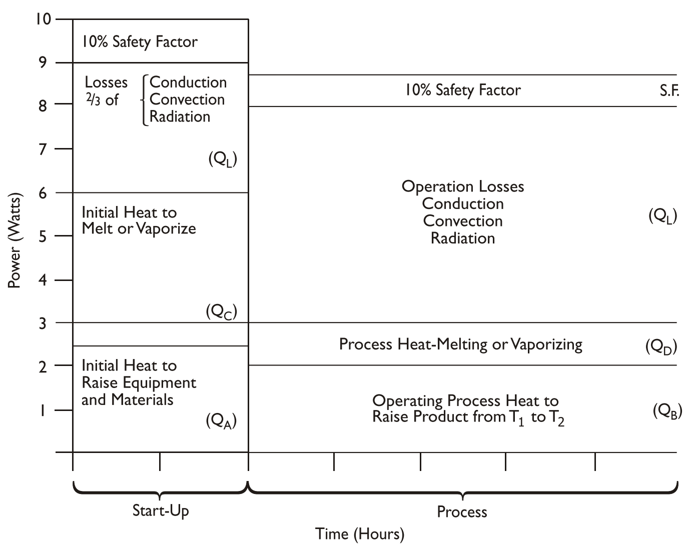
Power Evaluation

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



Hitco

Application Guide

Electric Heaters

Review of Heater Application Factor

Safe/Permissible Watt Densities

A heater's watt density rating gives us an indication of how hot a water 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 required for heating a 150°C (300°F) block.

From the silicone Rubber heater watt density chart in the flexible heater section of the Hitco Heater.

Maximum Watt Density = 16W/in^2 or wirewound on-off (2.5W/in^2) or 38W/in^2 (6W/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 9two 3 inch   5 inch heaters) are required.

Mechanical Consideration

Full access must be provided (in the design process) for ease of heaters 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 Factor

- 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 situation that affect heater life. Some heater construction are better sealed against contaminants than other. In analyzing applications, al 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 material that will contact the heaters 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, and should be consulted in order to avoid using materials that are not compatible with a particular environment.
- Explosive environment 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.

Hitco

Application Guide

Electric Heaters

Review of Heater Application Factor

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 influence 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 system 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 Ref. 2

Below are the estimated life expectancies for mineral insulated heater types: TUBULAR and High Density.

Ref. 2

Internal Element Temperature °C	(°F)	Approximate Life
815	(1500)	3 ½ Yrs.
870*	(1600)	1 Yr. (2000 hr.)
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 life greater than one year.

Heater 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 30to 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.

For Immersion Heaters

Use the corrosion Guide and the selection Guides in the Tubular Elements and Assemblies section of the Hitco Heater Catalog, 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 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.

Hitco

Application Guide

Electric Heaters

Review of Heater Application Factor

Electrical Lead Consideration

General consideration in selecting various lead types are :

- Temperature of lead area
- Contaminants in the lead area
- Flexibility Required
- Abrasion resistance required.
- Relative Cost

Temperature listed indicate actual physical operating limits of various wire types. Wire are sometimes rated by CSA, UL ® and other agencies for operating at much lower temperature. 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 Condute	————	Good	Average	Excellent	Moderate
Lead Insulation					
Ceramic Beads	650 (1200)	Poor	Poor	Average	High
Mica-Gass Bead (Silicone or Telflon® Impregnated)	540 (1000)	Poor	Poor	Average	High
Glass Braid (Silicone Impregnated)	400 (750)	Poor	Poor	Average	Low
Silicone Rubber	260 (500)	Good	Good	Good	Low
Telflon®	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
- Machine 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 time 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 product after heater failure and during restart of process.
- Frequency of burnouts

Hitco

Application Guide

Electric Heaters

Review of Heater Application Factor

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 : Case 2 : Shrouded and Insulated = 2.38 kW/H

Actual 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.

Hitco

Application Guide

Electric Heaters

Reference Data

Volts

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

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

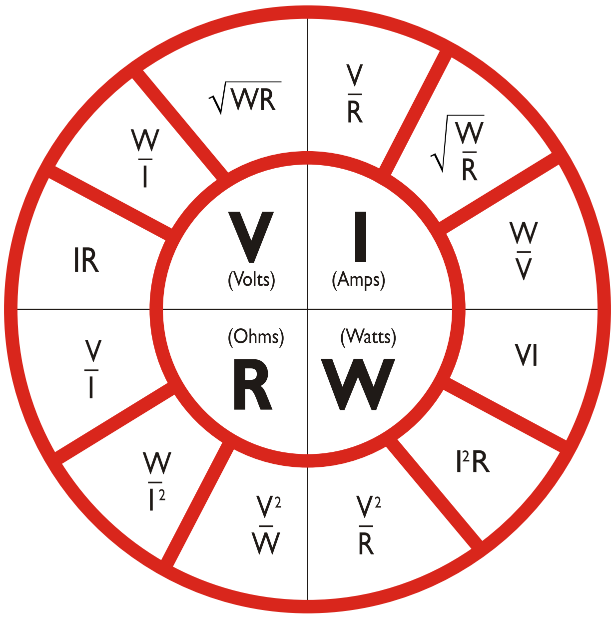
Volts = Amperes x Ohms

Amperes

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

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

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



Ohms

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

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

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

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

Typical 3-Phase Wiring Diagrams and Equations for Resistive Heaters

Definitions

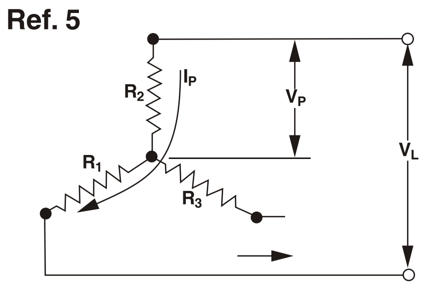
For Both Wye and Delta (Balanced Loads)

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

$W_{DELTA} = 3 W$
$W_{ODELTA} = W_{DELTA}$
$W_{OWYE} = ½ W_{WYE}$

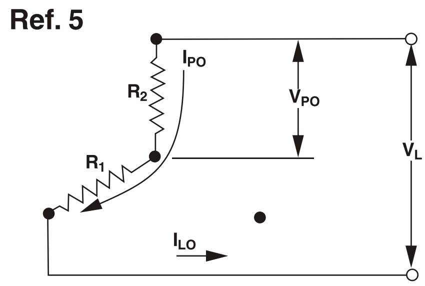
3-Phase Whye (Balanced Load)



Equations For Why Only

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

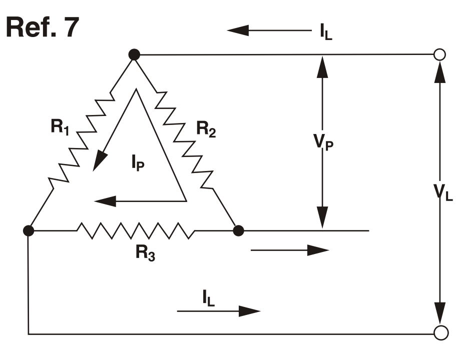
3-Phase Open Wye (No Neutral)



Equation For Open Wye Only
(No Neutra)

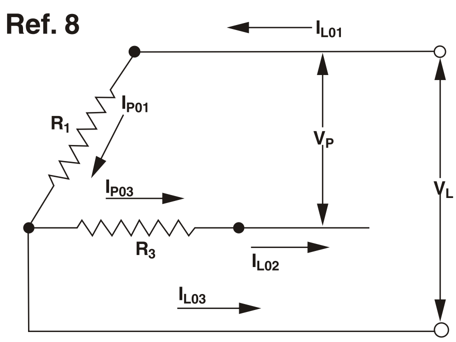
$I_{PO} = I_{LO}$
$V_{PO} = V_L/2$
$W_{OWYE} = ½(V_L^2/R)$
$W_{OWYE} = 2(V_{PO}^2/R)$

3-Phase Whye (Balanced Load)



Equations For Delta Only

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



Equation For Open Delta Only

$V_P = V_L$
$V_{PO1} = V_{LPO3} = I_{LO2}$
$W_{LO3} = 1.73\ I_{LPO1}$
$W_{0DELTA} = 2(V_L^2/R)$

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

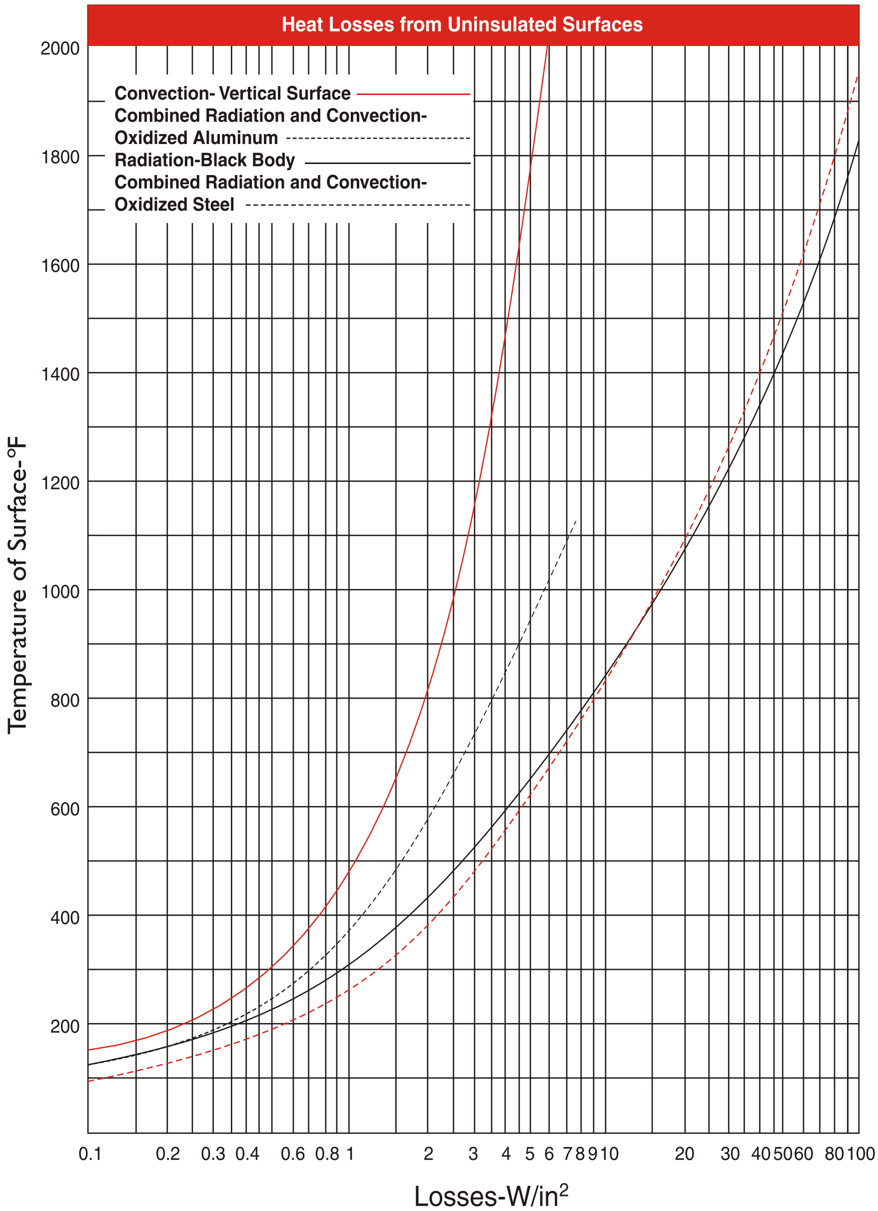
Radiation Curve Correction Factors

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



Hitco

Application Guide

Electric Heaters

Heat Loss Factors

and Graphs

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/in^2) =

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

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 - ft^2-°F. Use only for surfaces less than 800°F).

Losses (W/in^2)=

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

Some Material Emissivities / Non-Metal - Ref.11

Material	Specific Heat Btu/ib-°F	Emissivilty		
		Polished Surface	Medium Oxide	Heavy Oxide
Blackbody			0.75	1.00
Aluminum	0.24	0.09	0.11	1.22
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	0.95
Lead, solid	0.03	-	0.29	-
Magnesium	0.29	-	-	-
Nickel 200	0.11	-	-	-
Nichrome, 80-20	0.11	-	-	-
Solder, 50-50	0.04	-	-	-
Steel	0.12	0.10	0.75	0.85
mild	0.11	0.17	0.57	0.85
stainless 304	0.11	0.17	0.57	0.85
stainless 430				
Tin	0.056	-	-	-
Zinc	0.10	-	0.25	-

Some Material Emissivities/Non-Metal-Ref.11

Material	Specific Heat Btu/IB-°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	

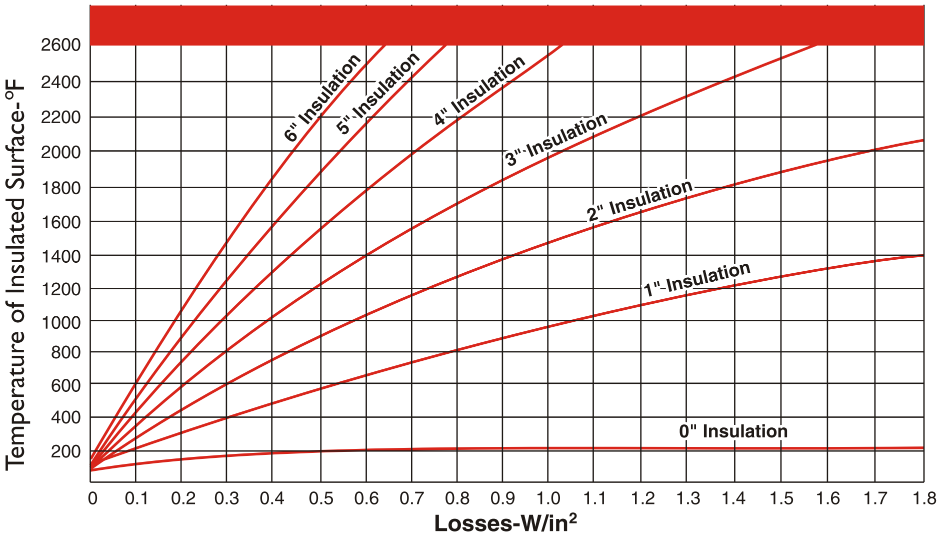
Additional information on emissivities is available from Hitco.

Application Guide

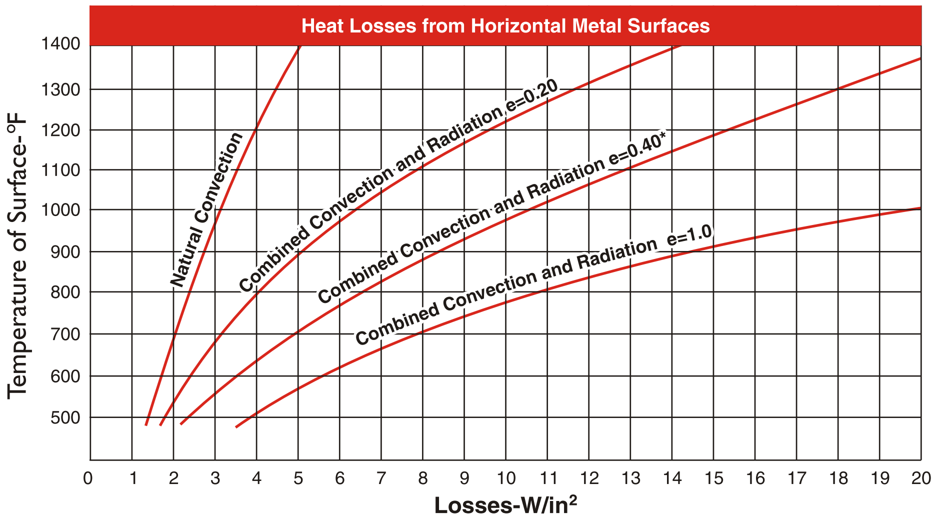
Electric Heaters

1. Bassed upon combined natural convection and radiation losses into 70°F environment
2. Insulation characteristics
   k= 0.7 @ 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 0.79For losses of molten metal surfaces, use the curve e=0.40

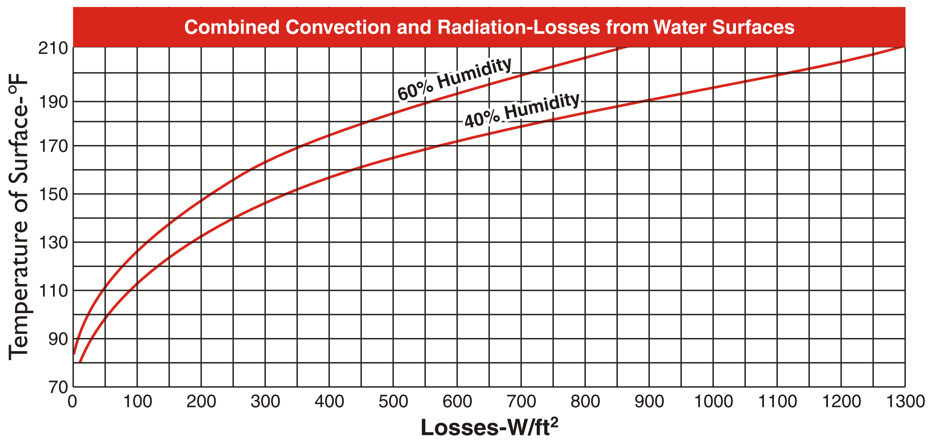
Ref. 12



Ref. 13



Ref. 14



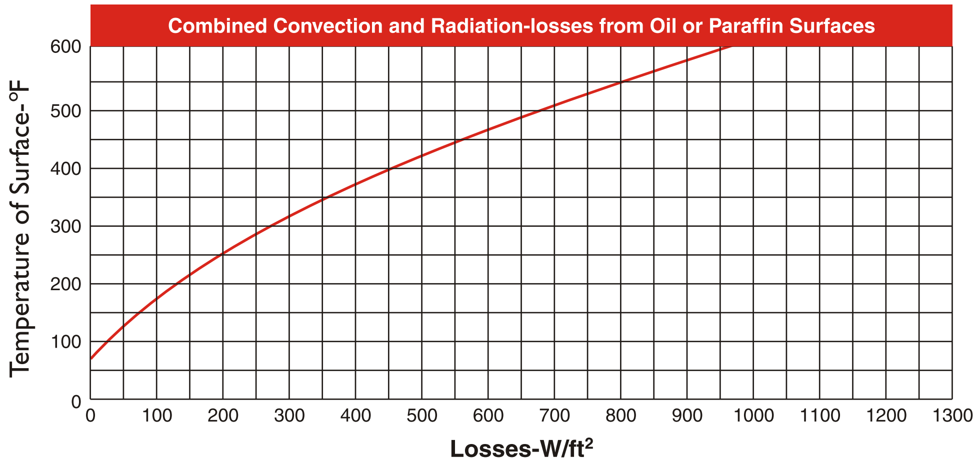
Hitco

Application Guide

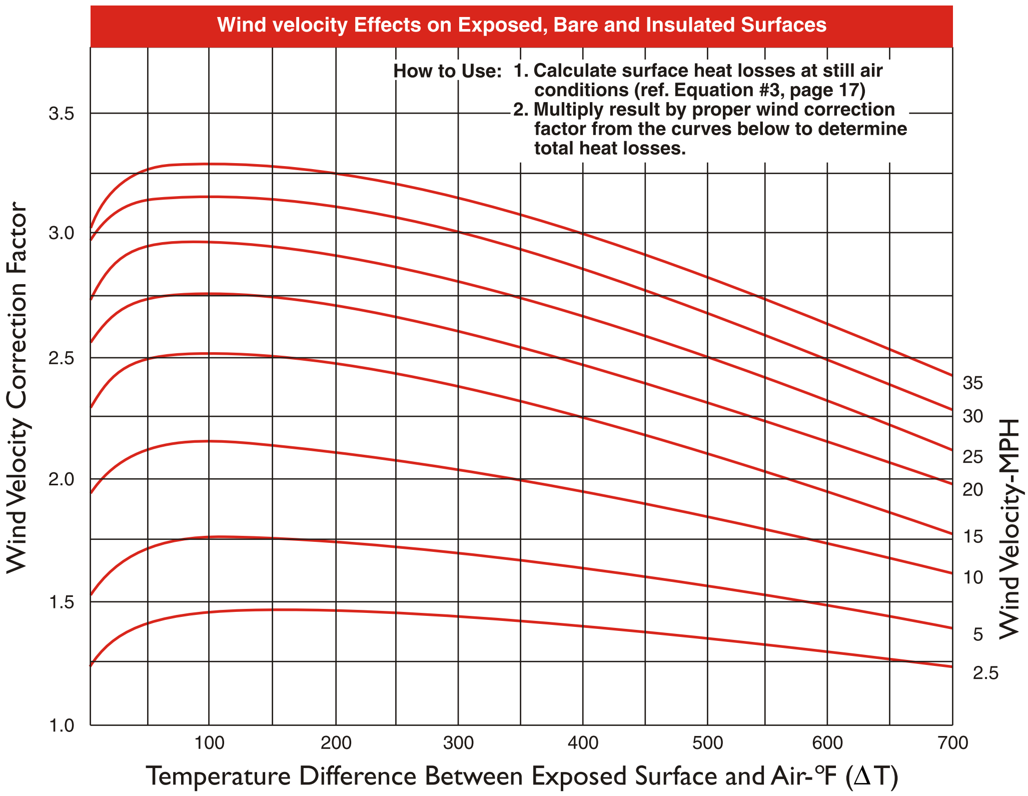
Electric Heaters

Heat Loss Factors and Graphs

Ref. 15



Ref. 16



Hitco

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 of metric equation.

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

$$kW = \frac{\text{Pounds} \times \text{Temperature Rise } (^\circ F)}{20.000 \times \text{Heat-up Time (hrs.)}}$$

Kilowatt-Hours to Heat Steel* - Ref.17

Amount of Steel (ib.)	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	0.02	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	500	10.00	15.00	20.00	25.00	30.00

Kilowatt-Hours to Heat Steel* - 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	2225	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

For Oil :
Use equation or table.

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

OR

$$kW = \frac{\text{Liters} \times \text{Temperature Rise } (^\circ C)}{1660 \times \text{Heat-up time (hrs.)}}$$

cu. ft = 7.49 gallons

* Read across in table from nearest amount in gallons of liquids to desired temperature rise column and not kilowatts to heat in one hours.

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 of metric equation.

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

$$kW = \frac{\text{Pounds x Temperature Rise (°F)}}{\text{20.000 x Heat-up Time (hrs.)}}$$

For Oil :
Use equation or table.

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

OR

$$kW = \frac{\text{Liters x Temperature Rise (°C)}}{\text{1660 x Heat-up time (hrs.)}}$$

cu. ft = 7.49 gallons

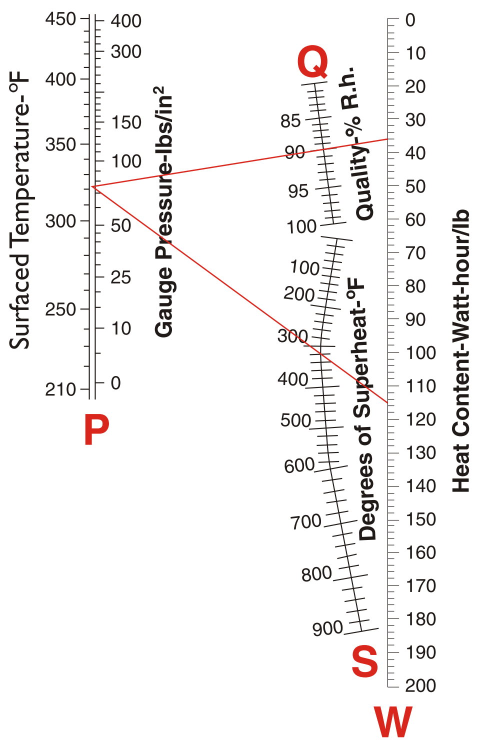
Kilowatt-Hours to Heat Water*- Ref. 19

Amount of Liquid		Temperature Rise °F						
ft^3	Gallons	20°	40°	60°	80°	100°	120°	120°
		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

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 W2
4. Required watts = Weight (lbs.) of steam/ hour x (W2-W1)

Watt density is critical Review tem-perature and velocity prior to heater selection. Reference is 80 percent quality at 20 psig.



Hitco

Application Guide

Electric Heaters

Quick Estimates of Wattage Requirements

Kilowatt-Hours to Heat Water*- Ref. 21

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

$$kW = \frac{CFM^{*} \times \text{Temperature Rise } (^{\circ}C)}{300}$$

OR

$$kW = \frac{\text{Cubic Meters/Min}^{*} \times \text{Temperature Rise } (^{\circ}F)}{47}$$

For Compressed Air:

$$kW = \frac{CFM^{**} \times \text{Density}^{**} \times \text{Temperature Rise } (^{\circ}F)}{288}$$

OR

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

* Measured at normal temperature and pressure.
** Measured at heater system inlet temperature and pressure.

Hitco

Application Guide

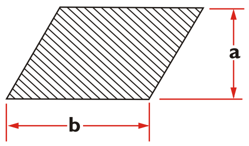
Electric Heaters

Reference Data

Commonly Used Geometric Areas And Volumes
Areas and Dimensions of Plane Figures

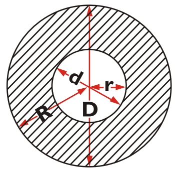
Ref. 131 The following illustrations show the areas of plane figures, the surfaces of solids, and the volumes of solids.

Square, Rectangle, Parallelogram

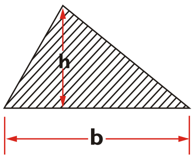


A = area
A = ab
Note that dimension a is measured at right angles to line b

Circular Ring



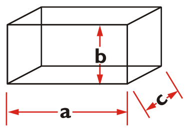
Triangle



A = area

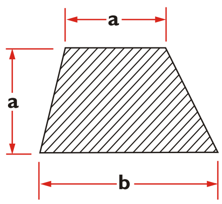
$A = \frac{bh}{2}$

Cub e or Squre Prism



V = volume
S = area of surface
V = abc
A = 2 ab + 2bc

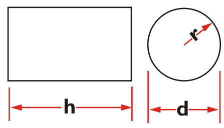
Trapezoid



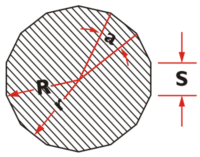
A = area

$A = \frac{(a+b)h}{2}$

Cylinder



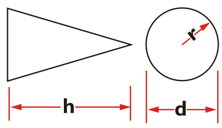
Regular Polygon



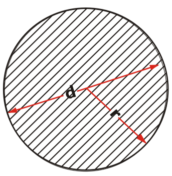
A = area
n = number of sides
s = length of side
$a = 360^{\circ} \div n$

$A = \frac{nsr}{2} = \frac{ns}{2}\sqrt{R^2 - \frac{S^2}{2}}$

Cone



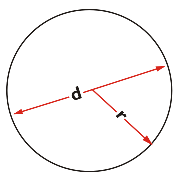
Circle



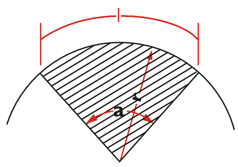
A = area
C = circumference

$\frac{d^2}{2}$

Sphere



Circular Sector



A = ½rl

$a = \frac{57.3l}{r}$

Hitco

Application Guide

Electric Heaters

Physical Properties of Solids Liquids and Gases

Properties of Non-Metallic Solids-Ref. 132

Material	*Density lb./ft³	Specific Heat Btu/lb.-°F	*Thermal Conductivity Btu-in./hr.-ft²-°F	Melting Point °F (Lowest)	Latent Heat of Fusion Btu/lb.
Allyl, Cast	82.5	0.55	12.1		
Alumina 96%	232	0.20	110.9	3812	
Alumina 99.9%	249	0.20	270	3812	
Aluminum Silicate (Leva Grade A)	149	0.2	9.1	3690	
Aluminum Nitride	199	0.19	1179	3992	
Amber	65.6				
Asbestos	36	0.25	0.44		
Ashes	40-45	0.2	0.49		
Asphalt	65	0.4	1.2	250±	40
Bakelite Resin, Pure	74-81	0.3-0.4			
Barium Chloride	240	0.10		1697	
Beeswax	60		1.67	144	75
Boron Nitride (Compacted)	142	0.33	125	5430	
Brick, Common Clay	100	0.23	5		
Brick, Facing/Building & Motors	140	0.22	8		
Calcium Chloride	157	0.17		1422	72
Carbon	138	0.20	165	6700	
Carnauba Wax	62.4	0.8			
Cement, Portland Loose	94	0.19	2.04		
Cerafelt Insulation	3	0.25 @1000°	1.22		
Ceramic Fiber	10-15	0.27	**		
Chalk	112-175	0.215	576		
Charcoal Wood	17.5-36	0.242	0.6121		
Chrome Brick		0.17	9.6		
Clay	90±10	0.224	9	3160	
Coal (Course Anthercite)	80	0.32	11		
Coal Tars	78	0.35-0.45			
Coke	62-88	0.265			
Concrete (Cinder)	100	0.16	5.3		
Concrete (Stone)	144	0.156	9.5		
Cordierite (AISI MAG 202)	131	0.35	9.12	2680	
Cork	13.5	0.5	.0.36		
Cotton (Flax Hemp)	92.4	0.31	0.41		
Delrin	88	0.35	1.56		
Diamond	219	0.147	13872		
Earth, Dry & Packed	94	0.44	0.9		
Ethyl Cellulose	67-74	0.32-0.46			
Fiberglass Microlite Duct Insulation	0.75		0.28		
Fiberglass Spin-Glas 1000 Insulation	3		0.26		

* At or near room temperature

** Thermal conductivity will decrease with age and use

To convert to kg/m³ multiply lb/ft³ by 16.02

To convert to kJ/kg multiply Btu/lb by 2.326

To convert to kJ/kg-°C multiply Btu/lb-°F by 4.187

To convert to W/m-°C multiply Btu-in/hr-ft²-°F by 0.1442

CONTINUED

Hitco

Application Guide

Electric Heaters

Physical Properties of Solids Liquids and Gases

Continued

Metarial	*Density ib./ft^3	Specific Heat Btu / ib.-°F	*Thermal Conductivity Btu / hr.-ft^2-°F	Metting Point °F (Lowest)	Latent Heat of Fusion Btu/lb.
Firebrick, Fireclay	137-150	0.243	6.6	2900	
Firebrick, Silica	144-162	0.258	7.2	3000	
Flourspar		0.21			
Forsterite (AISI Mag 243)	175		25.5	3470	
Garnet		0.176			
Glass	165	0.20	5.4	2220	
Granite	160-175	0.192	13-28		
Graphite	130	0.20	1.25	1202 (Sublimination)	
Ice	57	0.46	15.36	32	
Isoprene (Nat'l Rubber)	58	0.48	1.0		
Limestone	130-175	0.217	3.6-9	1472	
Litharge		0.055		1627	
Magnesia	225	0.234	0.48	5070	
Magnesite Brick	159	0.222	10.8-30		
Magnesium Oxide					
Before Compaction	147	0.21	3.6	5165	
After Compaction	190	0.21	14.4	5165	
Magnesium Silicate	175		15.6		
Marbel	150-175	0.21	14.4		
Marinite I @ 400°F	46	0.29	0.89		
Melamine Formaldehyde	93	0.4	3		
Mica	185	0.20	3		
Nylon Fibers	72	0.4-0.5			
Paper	58	0.45	0.82		
Paraffin	56	0.70	1.56	133	63
Phenolic Resin, Cast	84	0.3-0.4	1.1		
Phenolic Formaldehyde	78-92	0.38-0.42			
Phenolic, Sheet or Tube					
Laminated	78	0.3-0.5	2.4	300±	
Pitch, Hard	83				
Plastics:					
ABS	69-76	0.35	1.32		
		2.28			
Acrylic	69-74	0.34	1.0		
Cellulose Acetate	76-83	0.3-0.5	1.2-2.3		
Cellulose Acetate					
Butyrate	74	0.3-0.4	1.2-2.3		
Epoxy	66-88	0.25-0.3	1.2-2.4		
Fluoroplastics	130-150	0.28	1.68		
Nylon	67-72	0.3-0.5	1.68		
Phenolic	85-124	0.35	1.02		
Polycarbonate	74-78	0.3	1.38		
Polyester	66-92	0.2-0.35	3.96-5		
Polyethylene	57-60	0.54	2.28		
	3.48				
Polyimides	90	0.27-0.31	2.5-6.8		
Polypropylene	55-57	0.46	1.72		

CONTINUED

Hitco

Application Guide

Electric Heaters

Physical Properties of Solids Liquids and Gases

Continued

Metarial	*Density ib./ft^3	Specific Heat Btu / ib.-°F	*Thermal Conductivity Btu / hr.-ft^2-°F	Metting Point °F (Lowest)	Latent Heat of Fusion Btu/lb.
Plastics:					
Polystyrene	66	0.32	0.36-0.96		
Polyvinyl Chloride Acetate	72-99	0.2-0.3	0.84-1.2		
Porcelain	145-155	0.26	6-10		
Potassium Chloride	124	0.17		1454	
Potassium Nitrate	132	0.26		633	
Quartz	138	0.26	9.6	3137	
Rock Salt		0.219		1495	
Rubber Synthetics	58	0.40	1.0		
Sand, Dry	88-100	0.191	2.26		
Silica (fused)	124	0.316	10.0	3137	
Silicon Carbide	112-125	0.20-0.23	866	4892 (sublimination)	
Silicone Nitride	197	0.16	208	3452 (sublimination)	
Silicone Rubber	78	0.45	1.5		
Soapstone	162-174	0.22	11.3		
Sodium Carbonate	135	0.30		520	
Sodium Chloride	135	0.22		1474	
Sodium Cyanide	94	0.30		1047	
Sodium Hydroxide Bath (75% NaOH and Mixed Salts)	110	0.28		550	72
Sodium Nitrate	141	0.29		584	
Sodium Nitrite	135	0.30		520	
Sodium/Potassium					
Nitrate Baths:					
Draw Temp 275					
Solid	132	0.32		275	94
Liquid	110	0.37	2.4± @ 600°F		
Draw Temp 430					
Solid	130	0.29		430	49
Liquid	115	0.38	2.4± @ 600°F		
Soil, Dry Including Stones	127	0.40	3.6		
Steatite	162	0.20	17.4	2500	
Stone		0.20			
Stone, Sandstone	130-150	0.22			
Sugar	105	0.30		320	
Sulphur	125	0.203	1.8	230	17
Tallow	60			90±	
Teflon®	135	0.25	1.7		
Urea, Formaldehyde	97	0.4			
Vinylidene	107	0.32			
Vinylite	73	0.29			
Wood, Oak	50	0.57	1.2		
Wood, Pine	34	0.67	0.9		
Zirconia	368	0.12	17.3	4892	

CONTINUED

Hitco

Application Guide

Electric Heaters

Physical Properties of Solids Liquids and Gases

Continued

Properties of Metals - Ref. 133

Metarial	Density ib./ft^3	Specific Heat Btu / ib.-°F	*Thermal Conductivity Btu / hr.-ft^2-°F	Metting Point °F (Lowest)	Latent Heat of Fusion Btu/lb.	Thermal Expansion in/in°F X10^{-6}
Aluminum 1100-0	169	0.24	1536	1190	169	13.1
Aluminum 2024	173	0.24	1344	935	167	12.6
Antimony	413	0.049	131	1166	69	5.0
Babbitt-Lead Base	640	0.039	165.6	470		10.9
Babbitt-Tin Base	462	0.071	278.4	465		
Barium	225	0.068		1562	24	10.0
Beryllium	113.5	0.052	1121.0	2345	58	6.6
Bismuth	610	0.031	59	520	22.4	7.4
Boron	144	0.309		4172	898	4.6
Brass (80-20)	535	0.091	82	1700±		
Brass (70-30)	525	0.10	672	1700±		10.6
Brass (Yellow)	529	0.096	828	1710		11.2
Bronze (75% Cu, 25% Sn)	541	0.082	180	1832	75	
Cadmium	540	0.055	660	610	23.8	17.2
Calcium	96.7	0.149	912	1564	140	12.2
Carbon	138	0.165	173	>6422		2.3
Carboloy (Cemented Carbide)	875	0.052	420	>6422		
			636			
Chromium	450	0.11	484	2822	111.7	3.6
Cobalt	554	0.099	499	2696	115.2	6.9
Constantan (55% Cu, 45% Ni)	555	0.098		2237-2372		8.3
Copper	559	0.10	2688	1981	91	9.8
German Silver	537	0.109	168	1761	44.2	10.6
			204			
Gold	1203	0.030	2028	1945	29	7.9
Incoloy 800	501	0.12	97	2475		7.9
Inconel 600	525	0.11	109	2470		5.8
Invar 36% Ni	506	0.126	73	2600		1.1
Iron, Cast	450	0.13	396	2300±	40	6.0
Iron, Wrought	480	0.12	432	2800±		
Lead	708	0.032	240	620	9.8	16.4
Linotype	627	0.04		480		
Lithium	367	0.79	516	367	59	31
Magnesium	109	0.232	1092	1202	155	14.0
Manganese	463	0.115	80.6	2268	116	12.7
Mercury	844	0.033	60.8	-38	5.0	33.8
Molybdenum	638	0.061	980	4750	126	2.9

CONTINUED

★ At or near room temperature
To convert to kg/m³ multiply lb/ft³ by 16.02
To convert to kJ/kg multiply Btu/lb by 2.323
To convert to kJ/kg-°C multiply Btu/lb-°F by 4.187
To convert to W/m-°C multiply Btu-in/hr-ft^2-°F by 0.1442

Hitco

Application Guide

Electric Heaters

Physical Properties of Solids Liquids and Gases

Continued

Metarial	Density ib./ft^3	Specific Heat Btu / ib.-°F	*Thermal Conductivity Btu / hr.-ft^2-°F	Metting Point °F (Lowest)	Latent Heat of Fusion Btu/lb.	Thermal Expansion in/in°F X10^{-6}
Monel® 400	551	0.11	151	2370		6.4
Muntz Metal (60% Cu, 40% Zn)	523	0.096	852	1660		11.5
Nickel 200	554	0.011	468	2615	1335.8	7.4
Nichrome (80% Nil, 20% Cr)	524	0.11	104.4	2550	7.3	7.8
Platinum	1338	0.32	492	3225	49	4.9
Potassium	750	0.058	720	146	26.2	4.6
Rhodium	776	0.059	636	3570	90	4.7
Silicon	14.5	0.162	600	2570	709	4.2
Silver	655	0.057	2904	1760	38	10.8
Sodium	60	0.295	972	207	49.5	39
Solder (50% Sn, 50% Pb)	552	0.040	336	420	17	13.1
Solder (60% Sn, 40% Pb)	540	0.045	355	375	28	13.3
Steel, Mild Carbon	490	0.12	456	2760		6.7
Steel Stainless 304, 316, 321	500	0.12	105.6	2550		9.6
Steel, Stainless 430	475	0.11	150	2650		6.0
Tantalum	1036	0.036	372	5425	74.8	3.6
Tin	455	0.056	432	450	26.1	13.0
Titanium	283	0.126	111.6	3035	156.9	4.7
Tungsten	1200	0.032	1130	6170	79	2.5
Type Metal (85% Pb, 15% Sb)	670	0.040	180	500	14	
Uranium	1170	0.028	193.2	3075	22.5	7.4
Zinc	445	0.095	112 264	787	43.3	22.1
Zirconium	400	0.066	145	3350	108	3.2

* At or near room temperature
To convert to kg/m³ multiply lb/ft³ by 16.02
To convert to kJ/kg multiply Btu/lb by 2.326
To convert to kJ/kg-°C multiply Btu/lb-°F by 4.187
To convert to W/m-°C multiply Btu-in/hr-ft²-°F by 0.1442

Hitco

Application Guide

Electric Heaters

Physical Properties of Solids Liquids and Gases

Continued

Properties of Metals in Liquid State - Ref. 134

Material	Melting Point °F (°C)	Heat of Fusion Btu/lb.	Temperature °F	Density lb./ft³	Specific Heat Capacity Btu/lb.-°F	Thermal Conductivity Btu-in./hr.-ft²°F
Aluminum	1220.4 (660.2)	173	1220	148.6	0.26	
			1292	147.7	0.26	717
			1454		0.26	842
Bismuth	520 (271)	21.6	572	626.2	0.034 @ 520°F	119
			752	618.7	0.0354	107.4
			1112	603.1	0.0376	107.4
Cadmium	609 (321)	23.8	626	500	0.0632	
			662	498.8	0.0632	307.7
			680		0.0632	305
			752	495	0.0632	
Gold	1945 (1063)	26.9	2012	1076	0.0355	
Lead	621 (327.4)	10.8	700	655.5	0.038	111.6
			932	648.7	0.037	107.4
Lithium	354 (179)	284.4	392	31.7	1.0	262
			752	31	1.0	
Magnesium	1204 (651)	148	1204	98	0.317	
			1328	94.3		
			1341		0.321	
Mercury	-38 (-38.9)	5	32		0.03334	57
			212	833.6	0.03279	
			320			81
			392	818.8	0.03245	
Potassium	147 (63.8)	26.3	300	50.6	0.1901	312
			752	46.6	0.1826	277.5
Silver	1761 (960.5)	44.8	1761	580.6	0.0692	
			1832	578.1	0.0692	
			2000	574.4	0.0692	
Sodium	208 (97.8)	48.7	212	57.9	0.331	596.5
			400	56.2	0.320	556.8
			752	53.3	0.301	493.8
Tin	449 (231.9)	26.1	482		0.058	
			768	426.6		
			783			229.3
Zinc	787 (419.5)	43.9	787	432	0.12	
			932			400.6
			1112	425	0.117	394.8
Solder						
0.5 Sn, 0.5Pb	421 (216)	17			0.0556	
0.6 Sn, 0.4Pb	375 (190.6)	23			0.0584	

To convert to kg/m3 multiply lb/ft3 by 16.02
To convert to kJ/kg multiply Btu/lb by 2.326
To convert to kJ/kg-oC multiply Btu/lb-oF by 4.187
To convert to W/m-oC multiply Btu-in/hr-ft2-oF by 0.1442

Hitco

Application Guide

Electric Heaters

Physical Properties of Solids Liquids and Gases

Continued

Properties of Liquids-Ref. 135

Substance	*Density lbs./ft³	Specific Heat Btu / lb.-°F	*Thermal Conductivity Btu-in. / hr.-ft²-°F	Boiling Point °F	Heat of Vaporization Btu/lb.
Acetic Acid, 100%	65.4	0.48	1.14	245	175
Acetone, 100%	49.0	0.514	1.15	133	225
Allyl Alcohol	55.0	0.665		207	293
Ammonia, 100%	47.9	1.1	3.48	-27	589
Amyl Alcohol	55.0	0.65		280	216
Aniline	64.6	0.514	1.25	63	198
Arochlor Oil	89.7	0.28		650	
Brine-Calcium Chloride, 25%	76.6	0.689	3.36		
Brine-Solium Chloride, 25%	74.1	0.786	2.88	220	730
Butyl Alcohol	45.3	0.687		244	254
Butyric Acid	50.4	0.515		345	
Carbon Tetrachloride	98.5	0.21		170	
Corn Syrup, Dextrose	87.8	0.65±		231	
Cottonseed Oil	59.2	0.47	1.2		
Ether	46.0	0.503	0.95	95	160
Ethyl Acetate	51.5	0.475		180	183.5
Ethyl Alcohol, 95%	50.4	0.60	1.3		370
Ethyl Bromide	90.5	0.215		101	108
Ethyl Chloride	57.0	0.367		54	166.5
Ethyl Iodide	113.0	0.161		160	81.3
Ethylene Bromide	120.0	0.172		270	83
Ethylene Chloride	71.7	0.299		240	139
Ethylene Glycol	70.0	0.555		387	
Fatty Acid-Aleic	55.4	0.7±	1.1	547	
Fatty Acid-Palmitic	53.1	0.653	0.996	520	
Fatty Acid-Stearic	52.8	0.550	0.936	721	
Fish, Fresh, Average	55-65	0.76			
Formic Acid	69.2	0.525		213	216
Freon 11	92.1	0.208	0.600	74.9	
Freon 12	81.8	0.232	0.492	-21.6	62
Freon 22	74.53	0.300	0.624	-41.36	
Fruit, Fresh, Average	50-60	0.88			
Glycerine	78.7	0.58	1.97	556	
Heptane	38.2	0.49		210	137.1
Hexane	38.2	0.6		155	142.5

CONTINUED

* At or near room temperature.
** Average value shown. Boils at various temperatures within the distillation range for the material. Verify exact value from application originator.

To convert to kg/m³ multiply lb/ft³ by 16.02
To convert to kJ.kg multiply Btu/lb by 2.326
To convert to kJ/kg-°C multiply Btu/lb-°F by 4.187
To convert to W/m-°C multiply Btu-in/hr-ft2-°F by 0.1442

Hitco

Application Guide

Electric Heaters

Physical Properties of Solids Liquids and Gases

Continued

Substance	*Density lbs./ft³	Specific Heat Btu/lb.-°F	*Thermal Conductivity Btu-in./hr.-ft2-°F	Boiling Point °F	Heat of Vaporization Btu/lb.
Honey		0.34			
Hydrochloric Acid, 10%	66.5	0.93		221	
Ice	56	0.5	3.96		
Ice Cream		0.70			
Lard	57.4	0.64			
Linseed Oil	57.9	0.44		552	
Maple Syrup		0.48			
Meat, Fresh, Average	90±	0.70			
Mercury	845	0.033	59.64	675	117
Methyl Acetate	54.8	0.47		133	176.5
Methyl Chloroform	82.7	0.26		165	95
Methylene Chloride	82.6	0.288		104	142
Milk, 3.5%	64.2	0.90			
Molasses	87.4	060		220±	
Nitric Acid, 7%	64.7	0.92		220	918
Nitric Acid, 95%	93.5	0.5		187	207
Nitrobenzene		0.35		412	142.2
Olive Oil	58	0.47		570	
Perchlorethylene	101.3	0.21		250	90
Petroleum Products:					
Asphalt	62.3	0.42	5.04		
Benzene	56	0.42	1.04	175	170
Fuel Oils:					
Fuel Oil #1 (Kerosene)	50.5	0.47	1.008	**440±	86
Fuel Oil #2	53.9	0.44	0.96		
Fuel Oil Medium #3, #4	55.7	0.425	0.918	**580±	67
Fuel Oil Heavy #5, #6	58.9	0.41	0.852		
Gasoline	41-43	0.53	0.936	**280±	116
Machine/Lube Oils:					
SAE 10-30	55.4	0.43			
SAE 40-50	55.4	0.43			
Napthalene	54.1	0.396		424±	103
Paraffin, Melted (150°F+)	56	0.69	1.68	572	70
Propane (Compressed)	0.13	0.576	1.81	-48.1	
Toluene	53.7	0.42	1.032		
Transformer Oils	56.3	0.42	0.9		
Phenol (Carbolic Acid)	66.6	0.56		346	
Phosphoric Acid, 10%	65.4	0.93			
Phosphoric Acid, 20%	69.1	0.85			

CONTINUED

* At or near room temperature.

** Average value shown. Boils at various temperatures within the distillation range for the material. Verify exact value from application originator.

To convert to kg/m³ multiply lb/ft³ by 16.02
To convert to kJ.kg multiply Btu/lb by 2.326
To convert to kJ/kg-°C multiply Btu/lb-°F by 4.187
To convert to W/m-°C multiply Btu-in/hr-ft2-°F by 0.1442

Hitco

Application Guide

Electric Heaters

Physical Properties of Solids Liquids and Gases

Continued

Properties of Metals - Ref. 133

Material	Density lb./ft^3	Specific Heat Btu / lb.-°F	*Thermal Conductivity Btu-in / hr.-ft^2 °F	Melting Point °F (Lowest)	Latent Heat of Fusion Btu/lb.	Thermal Expansion in/in/°F X10^{-6}
Monel® 400	551	0.011	151	2370		6.4
Muntz Metal (60% Cu, 40% Zn)	523	0.096	852	1660		11.5
Nickel 200	554	0.11	468	2615	1335.8	7.4
Nichrome (80% Ni, 20% Cr)	524	0.11	104.4	2550	7.3	7.8
Platinum	1338	0.32	492	3225	49	4.9
Potassium	750	0.058	720	146	26.2	4.6
Rhodium	776	0.059	636	3570	90	4.7
Silicon	14.5	0.162	600	2570	709	4.2
Silver	655	0.057	2904	1760	38	10.8
Sodium	60	0.295	972	207	49.5	39
Solder (50% Sn, 50% Pb)	552	0.040	336	420	17	13.1
Solder (60% Sn, 40% Pb)	540	0.045	355	375	28	13.3
Steel, Mild Carbon	490	0.12	456	2760		6.7
Steel, Stainless 304,316, 321	500	0.12	105.6	2550		9.6
Steel, Stainless 430	475	0.11	150	2650		6.0
Tantalum	1036	0.036	372	5425	74.8	3.6
Tin	455	0.056	432	450	26.1	13.0
Titanium	283	0.126	111.6	3035	156.9	4.7
Tungsten	1200	0.032	1130	6170	79	2.5
Type Metal (85% Pb, 15% Sb)	670	0.040	180	500	14	
Uranium	1170	0.028	193.2	3075	22.5	7.4
Zinc	445	0.095	112	787	43.3	22.1
			264			
Zircomium	400	0.066	145	3350	108	3.2

* At or near room temperature.

** Average value shown. Boils at various temperatures within the distillation range for the material. Verify exact value from application originator.

To convert to kg/m^3 multiply lb/ft^3 by 16.02
To convert to kJ.kg multiply Btu/lb by 2.326
To convert to kJ/kg-°C multiply Btu/lb-°F by 4.187
To convert to W/m-°C multiply Btu-in/hr-ft2-°F by 0.1442

Hitco

Application Guide

Electric Heaters

Physical Properties of Solids Liquids and Gases

Continued

Properties of Gases-Ref. 136

Substance	*Density lb./ft³	*Specific Heat at Constant Pressure Btu/lb. - °F	*Thermal Conductivity Btu-in./hr.-ft²-°F
Acetylene	0.073	0.35	0.129
Air	0.076	0.240	0.18
Alcohol, Ethyl (Vapor)		0.4534	
Alcohol, Methyl (Vapor)		0.4580	
Ammonia	0.044	0.523	0.16
Argon	0.103	0.124	0.12
Butane	0.1623		0.0876
Butylene	0.148		
Carbon Dioxide	0.113	0.199	0.12
Carbon Monoxide	0.078	0.248	0.18
Chlorine	0.184	0.115	0.06
Chloroform		0.1441	0.046
Chloromethane	0.1309	0.24	0.0636
Dichlorodifluoromethane (F-12)	0.329	0.143	0.058
Ethyl Chloride	0.1703		0.066
Ethylene	0.0728	0.40	0.1212
Ethyl Ether		0.4380	0.0924
Helium	0.0104	1.25	1.10
Hydrochloric Acid	0.0946	0.191	
Hydrogen	0.0056	3.43	0.13
Hydrogen Sulfide	0.096	0.2451	0.091
Methane	0.0447	0.60	0.21
Nitric Oxide	0.0779	0.231	0.1656
Nitrogen	0.075	0.249	0.19
Nitrous Oxide	0.1143	0.221	0.1056
Oxygen	0.082	0.218	0.18
Sulfur Dioxide	0.179	0.155	0.07
Water Vapor (212°F)	0.0372	0.482	0.16

Properties of Air*-Ref. 137

Temperature (°F)	Specific Heat (Btu/lb. - °F)	Density (lb./ft³)
0	0.240	0.086
50	0.240	0.078
100	0.240	0.071
150	0.241	0.065
200	0.242	0.060
250	0.243	0.056
300	0.244	0.052
350	0.245	0.049
400	0.247	0.046
450	0.248	0.043
500	0.249	0.041
550	0.250	0.039

Temperature (°F)	Specific Heat (Btu/lb. - °F)	Density (lb./ft³)
600	0.252	0.037
650	0.253	0.035
700	0.254	0.034
750	0.256	0.033
800	0.257	0.032
850	0.258	0.030
900	0.260	0.029
950	0.261	0.028
1000	0.262	0.027
1050	0.264	0.026
1100	0.265	0.025
1150	0.266	0.025
1200	0.267	0.024

* At 60oF and atmospheric pressure (14.7 psia)
To convert to kg/m3 multiply lb/ft by 16.02
To convert to kJ/kg multiply Btu/lb by 2.326
To convert to kJ/kg-oC multiply Btu/lb-oF by 4.187
To convert to W/m-oC multiply BTU-in/hr-ft2-oF by 0.1442

Hitco

Application Guide

Electric Heaters

Corroslon Guide

The Hitco Corrosion Guide represents a compilation of available data and application experience on the relative compatibility of common heater sheath materials and corrodants. This can be valuable in the initial selection of a heater sheath material to be used with a listed corrodant. Final selection, however, should be made based upon the specific exposure conditions, recommendations of the corrosive agent's manufacturer and preliminary testing.

Rating System

A - Good

B - Fair

C - Conditional - Performance is dependent upon specific application conditions such as solution concentration and temperature.

X - Unsuitable-Should not be used.

Notes to Corrosion Guide

1. This solution involves a mixture of various chemical compounds whose identity and proportions are unknown knowledge. Check supplier to confirm choice of sheath material plus alternate sheath materials that may be used.
2. Caution-Flammable material.
3. Chemical composition varies widely. check supplier for specific recommendations.
4. Direct immersion heaters not practical. Use clamp-on heaters on outside surface of cast iron pot.
5. Element surface loading should not exceed 3 W/cm^2 ($20W/in^2$)
6. For concentrations greater than 15 percent, element surface loading should not exceed $3W/cm^2$ ($20W/in^2$).
7. See suggested watt density chart.
8. Remove Crusts at liquid level.
9. Clean often.
10. Do not exceed $2W/cm^2$ ($12 W/in^2$).
11. Passivate stainless steel, Inconel® and Incoloy®.

Note: Blank spaces indicate an absence of data to establish a rating.

Corrodant	Boiling Point B. P. °F	Auto Point F. P. °F	Auto Ignition A. I. °F	Iron Steel	Cast Iron Grey	Cast Iron NI Resist	Aluminum	Copper	Lead	Monel® 400	Nickel 200	304, 321, 347 Stainless Steel	316 Stainless Steel	Type 20 Stainless Steel	Inconoy® 800	Inconel® 600	Titanium	Hastelloy® B	Quartz	Graphite	Teflone®	Comments
Acetaldehyde	69	-33	365				B	X	B	B	B	A	A	A		B	A	C		A	A	Note 2
Acetic Acid	244	109	800	X	X		C	X	X	B	C	C	B	A	C	C	A		A	A	A	
Crude				X		C	A/B	B	X	B	B	A/B	A/B	A	C	C						
Pure						X	A	B	B	A	B	A	A		C	C				A	A	
Vapors						X	C	B	X	B	B	X	X	A	C	C	A/B	A		A	A	Hastelloy® C-276 Acceptable
150 PSI, 400°F							C	B	X	B	B				C	C						
Aerated				X	X	X	C	X	X	X	X	X	B	B		X	A					
No Air					X	X	C	B	X	A	B	C	B	B		X	A					
Acetone	134	0	1000	C	X	B	B	A	A/B	A	A	A	A	A	A	A	A	A	A	A	A	Note 2
Actane™ 70																				A	A	Note 1 TM: Enthone, Inc. Acid additive for picking of metals.
Actane™ 80																				A	A	Note 1
Actane™ Salt																				A		Note 1
Alboloy Process				A																		
Alcoa™ R5 Bright Dip																			A		A	Note 1 TM: Enthone, Inc. Acid additive for picking of metals.
Allyl Alcohol	207	70	713		A	A	B	A	B	A	A	A	A	A/B	A	A	A/B			A	A	
Alcohol				B	B		B	A	A	A	A	B	A	A	A	A	A	A	A	A		Note 2

Hitco

Application Guide

Electric Heaters

Corrodant	Boiling Point B. P. °F	Auto Point F. P. °F	Auto Ignition A. I. °F	Iron Steel	Cast Iron Grey	Cast Iron NI Resist	Aluminum	Copper	Lead	Monel® 400	Nickel 200	304, 321, 347 Stainless Steel	316 Stainless Steel	Type 20 Stainless Steel	Inconoy® 800	Inconel® 600	Titanium	Hastelloy® B	Quartz	Graphiite	Teflone®	Comments
Alocrite™																		A				Note1 TM:Fredrick Gumn Chemical Co. Aluminum conversion coating.
Alkaline Solutions				A								A										
Alkaline Cleaners												A									X	Note 1
Alkaline Soaking Cleaners				A																		Note 1
Alodine™													A									Note 1 TM:Amchem Products Inc. Protective coating chemical for aluminum.
200°F												A347	A									
Aluminum (Molten)	3732								Contact Factory													
Aluminum Acetate				X	X		B	B	A	B	B	A/B	A	A		B	A	A			A	
Aluminum Bright Dip																			A		A	Note 1
Aluminum Chloride	356			X	X		X	X	X	X	X	X	X	X	X	X	X	A	A	A	A	Note 1 Hastelloy® C-276 Acceptable
Aluminum Cleaners				C	C		X	X	X	A	A	A	A	B	A	A	B		X	X		Notes 1, 9
Aluminum Potassium																B						
Sulfate (Alum)					X	X	X	A/B	B	B	B	X	B/C	B		B	A/B			A	A	
Aluminum Sulfate				X	X	X	X	X	B	X	X	B	B	B	X	X	A	B	A	A	A	Note 1
Alum							See Aluminum Potassium Sulfate															
Ammonia				X	X		C	X	C	X	X	X	X	X	C	B	A	A	A	A		
Ammonia (Anhydrous)(Gas)	-28		1204	B			X	X		X		A	A	A				A		A	A	Hastelloy® C-276 Acceptable
Cold				C		A	A	A	B	A	A	A	A	A		A	A					
Hot				C		C		A	X	A	A	C	C	A		A						
Ammonia and Oil				A																		
Ammonium Acetate				A	B	B	A/B	X	X	X	A	A/B	A/B	A/B	A	A	B	B		A	A	
Ammonium Bifuoride				X	X		X	X	X	X	X	X	X	B	X	X	X	A	X	A	A	
Ammonium Chloride	640			X	X	B	X	X	X	B	B	X	C	C	C	C	A	A	A	A	A	Hastelloy® C-276 Acceptable
Ammonium Hydroxide				B	B	B	C	X	B	X	A	A	A	A/B	A	A	A		X	A	A	
Ammonium Nitrate				B/X	X	C	B	X	X	X	X	A	A	A	X	X	X		A	A	A	
Ammonium Persulfate				X	X		B/X	X	C	X	X	B/X	B	B		X	B	X	B	A	A	
Ammonium Sulfate				X	X	B	X	X	B	B	B	C	B	B	B	B	A	B	A	A		
Amyl Acetate	298	77	714	B			A	A/B		A	A	A	A	A	A	A	A	A		A	A	Hastelloy® C-276 Acceptable
Amyl Alcohol	280	91	572	A	B	B	C	A/B		A	B	A304	A/B	A/B	A	A	A/B		A	A	A	
Aniline	364	158	1418	B	A		B	X	B	B	B		A	A	B	B	A	B	A	A	A	
Aniline, Oil				A			X	X				A	A									

Hitco

Application Guide

Electric Heaters

Corrodant	Boiling Point B. P. °F	Auto Point F. P. °F	Auto Ignition A. I. °F	Iron Steel	Cast Iron Grey	Cast Iron NI Resist	Aluminum	Copper	Lead	Monel® 400	Nickel 200	304, 321, 347 Stainless Steel	316 Stainless Steel	Type 20 Stainless Steel	Inconoy® 800	Inconel® 600	Titanium	Hastelloy® B	Quartz	Graphite	Teflone®	Comments
Aniline, Dyes										A		A	A									
Anodizing				X	X		X	X	A	X	X	X	X	A	X	X	X		A	A	A	
Anodizing Solutions (10% Solution)																						
Chromic Acid 96°F				C								A	A				A					
Sulfuric Acid 70°F	626								A					A								
Sodium Hydroxide 160°F	2534			A				A			A		A	A	A		A					
Nigrosine 150°F Black Dye										C	B											
Nickel Acetate 200°F									C	A	B											
Arp™ 28																				A	A	Note 1 TM: Specialty Chemicals, Allied-Kelite Products Div., The Richardson Co.
Arp™ 80 Blackening Salt																				A		Note 1
Arsenic Acid				X	X		X	X	X	X	X	C	B	B	X	X	X		A	A	A	
Asphalt	<878	400 +	900	A	A		X	X	X	X	A/B	A/B	A	A	A	A	A		A	A	A	
Barium Chloride	2840						X				A	B	B			A	A	B		A	A	
Barium Hydroxide				B	B		X	X	X	B	B	B	A	A/B	B	B	X	B	A	A	A	Carpenter 20 Acceptable
Barium Sulfate				B	B	B	B	B	B	B	B	B	B	B	B	B	A	B	A	A	A	
Barium Sulfide (BariumMonosulfide)				B			X	X	A/X	A		A/B	B	B						A	A	
Barium Sulfite												B										
Black Nickel																			A		A	Note 5
Black Oxide												A										Note 5
Bleaching Solution (1 1/2lb. Oxalic Acid per gallon H2O at 212°F										A		F										
Bonderizing™ (Zinc Phosphate)				C		B						A	A									TM: Parker Div., OMI Corp., Paint Base
Boric Acid				X	X		X	C	C	C	C	C	C	C	C	C	A	A	A	A	A	Hastelloy® C276 Acceptable
Brass Cyanide												A										Note 1
Bright Copper-Acid See Copper Bright Acid																						
Bright Copper-Cyanide See Copper Cyanide																						
Bright Nickel																	A		A			Notes 1, 5
Brine (Salt Water)										A						B				A	A	
Bronze Plating				A								A										Note 1
Butanol (Buty/Alcohol)	243	84	689	A/B	A		B		A	A	A	A	A	A	A	A		B	A	A	A	Note 1
Cadmium Black																			A			Note 1
Cadmium Fluoborate																				A	A	Note 1
Cadmium Plating															A	A						Note 1
Calcium Chlorate																						

Hitco

Application Guide
Electric Heaters

Corrodant	Boiling Point B. P. °F	Auto Point F. P. °F	Auto Ignition A. I. °F	Iron Steel	Cast Iron Grey	Cast Iron NI Resist	Aluminum	Copper	Lead	Monel® 400	Nickel 200	304, 321, 347 Stainless Steel	316 Stainless Steel	Type 20 Stainless Steel	Incoloy® 800	Inconel® 600	Titanium	Hastelloy® B	Quartz	Graphite	Teflon®	Comments
Calcium Chloride	> 2912			B	B		C	B	X	B	B	B	B	B	B	B	A	A	A	A	A	Hastelloy® C276 Acceptable
Carbolic Acid (Pheno)	362	175	1319	B	B	B	B	X	B	B	B	C	X	B	B	B	A	A	A	A	A	Hastelloy® C276 Acceptable
Carbon Dioxide-Dry Gas				X	X	A	A	A	B	A	A	A/B	A/B	A	A	A	X	A	A	X	X	Hastelloy® C-276 Acceptable
Carbon Dioxide-Wet Gas				X	X	C	A	X	B	A	A	A/B	A/B	A/B	A	A	X	A	A	X	X	
Carbon Tetrachloride				X	X	C	X	C	A	A	A	C	B	B	A	A	A	A	A	A	A	Hastelloy® C-276 Acceptable
Carbonic Acid	359	175	1319	C	C		C	C	X	C	C	A/B	B	A	B	A	A		A	A	A	
Castor Oil	595	445	840	A	A		A/B	A	A	A	A	A/B	A/B	A	A	A	A		A	A	A	
Caustic Etch				A	A		X	X		A	A	A	A	X	X	X	A		A	A	X	
Caustic Soda (Lye) (Sodium Hydroxide)				X	X	A	X	X	X	C	C	X	C	C	C	B	C		X	A	A	Notes 6,8
2%				B	B	B	X	B	X	A	A	X	B	A	A	A	A					
10-30%, 210°F				B	B	A	X	B	X	A	A	A	A	A	A	A	A					
76%, 180°F				X	X	X	X	X	X	B	A	B	B	B	A	A	B					
Chlorine Gas:																						
Dry	-30			X	X	B	X	X	X	B	C	C/X	C	B	C	B	B/X	B	A	B	B	Note 2
Wet	-30			X	X	X	X	X	X	X	X	X	X	X	X	X	X		A	X	A/X	Note 2
Chloroacetic Acid (Monochloroacetic Acid)	372	None		X	X		X	X	X	B	B	X	X		C	C	A	A	A	A	A	Hastelloy® C-276 Acceptable
Chromic Acetate																			A			Note 1
Chromic Acid				X	C	X	X	X	B	X	X	X	X	X	X	X	A		A	A	X	
Chromium Plating				X	X		X	X	B	X	X	X	X	X	X	X	A		A	A	X	
Chromylite																			A			Note 1
Citric Acid				X	X	C	C	C	X	B	B	C	C	B	B	B	A	A	A	A	A	Hastelloy® C-276 Acceptable
Clear Chromate													A									Note 1
Cobalt Acetate at 130°F										B	B	A	A		B	B						
Cobalt Nickel																			A			Notes 1, 6
Cobalt Plating												A							A			Note 1, 6
Coconut Oil		420 Crude 548 Refined							B	A												
Cold Liver Oil		412					A				A	A	A	A	A	A						
Copper Acid																	A		A			Note 1
Copper Bright												A	A									Note 1
Copper Britht Acid																			A			
Sopper Chloride				X	X		C/X	X	C	X	X	X	X	X	X	X	A	B	A	A	A	
Copper Cyanide				A	A		X	X		C	X	B	B	B	X	X		B	A	A	A	
Copper Fluoborate										B	B	B	B	B	B	B				A	A	
Copper Nitrate				X	X	X	X	X		X	X	A/B	A/B	A/B	X	X		X	A	A	A	
Copper Plating				A																		
Copper Pyrophosphate												A										Note 1
Copper Strike				A	A							A										Note 1
Copper Sulfate				X	X	B	X	C/X	A	X	X	B	B	A/B	C	X	A	B	A	A	A	Hastelloy® C276 Acceptable

![Hitco]

Application Guide
Electric Heaters

Corrodant	Boiling Point B. P. °F	Auto Point F. P. °F	Auto Ignition A. I. °F	Iron Steel	Cast Iron Grey	Cast Iron NI Resist	Aluminum	Copper	Lead	Monel® 400	Nickel 200	304, 321, 347 Stainless Steel	316 Stainless Steel	Type 20 Stainless Steel	Incoloy® 800	Inconel® 600	Titanium	Hastelloy® B	Quartz	Graphite	Teflon®	Comments
Creosote	392 -482	165	637	A	B	B	C	B	X	B	B	B	B	B	B	B			A		A	Note 2
Cresylic Acid (Cresol)	376 -397	110		C	C		C	C	X	B	B	B	A	A	C	B	B	B	A	A	A	Note 2
Deionized Water				X	X		X	X		A	A	A	A	A	A	A	A					Note 11
Deoxidine												A										TM: Amchem Products, Inc. Metal cleaner, rust remover
Deoxylyte™												A										TM: Amchem Products, Inc.
Deoxidizer (Etching)																			A			Note 1
Deoxidizer (3AL-13)												A	A									Note 1 Non-Chrome
Dichromic Seal				X	X																	
Diethylene Glycol	474	255	444	B	A		B	B	A	B	B	A	A	A	B	B	A		A	A	A	
Diphenyl 300°F-350°F	491	235	1004	A	A	A	A	A	A	A	A	A		A		A	B	B				
Disodium Phosphate				A										B							A	
Diversey™-DS9333																			A			Note 1 TM: Amchem Products, Inc.
Diversey™99				A																		
Diversey™ 511																			A			Notes 1, 5
Diversey™ 514																				A	A	Note 1
Dowtherm™A				A																		TM: Dow Chemical Co. Heat transfer agent
Dur-Nu™																	A		A			Note 1, 5
Electro Cleaner				A								A										Note 1
Electro Polishing																			A			Note 1
Electroless Nickel																	A		A			Note 1
Electroless Tin																						
(Acid)																			A			Note 1
(Alkaline)													A				A					Note 1
Enthone Acid-80	_																			A	A	Note 1
Ether	94	-49	356	B	B		B	B	B	B	B	B	B	A	B	B	A		A			Note 2 Carpenter 20 Acceptable
Ethyl Chloride (No Water)	54	-58	966	B	B		B	A	B	B	A	B	B	A	B	A	A	B	A	A	A	Note 2
Ethylene Glycol	387	232	775	A	B		A	B	X	B	B	B	B	B	B	B	A	A	A	A	A	Note 5 Hastelloy® C-276 Acceptable
Fatty Acids				X	X		A	C/X	X	B	B	C/B	A	A	B	B	A	A	A	A	A	Carpenter 20 Accep., Hastleloy® C-276 Accep.
Ferric Chloride	606			X	X	X	X	X	X	X	X	X	X	X	X	X	A	C	A	A	A	
Ferric Nitrate				X	X		X	X		X	X	B	B	A	X	X		X	A	A	A	Carpenter 20 Acceptable
Ferric Sulfate				X	X	X	X	X	A/B	X	C	B	B	B	C	C	A	X	A	A	A	
Fluoborate																				A	A	Note I
Fluoborate (High Speed)																				A		Note I
Fluorine Gas, Dry	-305			C	X		C/X	X	X	A	A	C	A/C	A/C	C	A	A	B	C	X	X	
Formaldehyde	27	122 185	806	X	X	B	B	B	X	B	B	A	A	A	B	B	A		A	A	A	
Formic Acid	213	156	1114	X	X		X	B	X	C	C	X	C	A	B	C	X	A	A	A	A	Carpenter 20 Accep., Hastleloy® C-276 Accep.
Freon				A	A	A	A	A	A	A	A	A	A	A	A	A						
Fuel Oil-Normal				A	A		A/B	A	A	B	B	A/B	A/B	A	B	B	A	B		A	A	Notes 2, 3, 7

Hitco

Application Guide

Electric Heaters

Corrodant	Boiling Point B. P. °F	Auto Point F. P. °F	Auto Ignition A. I. °F	Iron Steel	Cast Iron Grey	Cast Iron NI Resist	Aluminum	Copper	Lead	Monel® 400	Nickel 200	304, 321, 347 Stainless Steel	316 Stainless Steel	Type 20 Stainless Steel	Inconoy® 800	Inconel® 600	Titanium	Hastelloy® B	Quartz	Graphite	Teflone®	Comments
Fuel Oil-Acid				X	X		X	X	X	C	C	C	B	A	C	C	A					Notes 2, 3, 7 Carpenter 20 Acceptable
Gasoline-Refined	280±	-45	495	A	A	A	A/B	A/B	A	B	B	A	A	A	B	B		B	A	A	A	Notes 2, 5
Gasoline-Sour				C	C		C	C	A	X	X	B	B	A	X	X		B	A	A	A	Notes 2, 3, 5 Carpenter 20 Acceptable
Glycerine (Glyceron)	254	320	739	B	C	B	A	B	B	A	A	A	A	A	A	A	A	A	A	A	A	Hastelloy® C-276 Acceptable
Gold-Acid				A													A		A			Note 1
Gold-Cyanide												A	A									Note 1
Grey Nicket																	A		A		A	Notes 1, 5
Holdene 310A Tempering Bath											A											
Hote Seal Sodium Dichromate													A									Note 1
Houghtone Mar Tempering Salt				C							C											
Hydrocarbons-Aliphatic				A	A		A	A		A	A	A	A	A	A	A			A	A		Note 2
Hydrocarbons-Aromatic				A	A		A	A		A	A	A	A	A	A	A			A	A		Note 2
Hydrochloric Acid (No Air)	-120																					
<150°F				X	X	X	X	X	X	X	X	X	X	X	X	X	X		A	A		
>150°F				X	X		X	X	X	X	X	X	X	X	X	X	X		A	A	A	
Hydrocyanic Acid (No Air)	78	0	100	X	X		B	X	X	B	B	B	B	B	B	B			A	A	A	
Hydrofluoric Acid	67																					
Cold <65%				X	X	X	X	X	X	C	X	X	X	C/X	X	X	X	C	X	A	A	Note 5
>65%				B	X	X	X	X	X	C	X	X	X	C	X	X	X	B		X	A	
Hot <65%				X			X	X	X	C	X	X										
>65%				X			X	X	X	C	X	X	X	X	X	X	X	C		X	A	
Hydrogen Peroxide				X	X	X	A	X	X	C	B	B	B	B	B	B	A	C	A	X	A	
Indium	3632																		A		A	Note 1
Iridite™ #4-75, # 4-73, #14, #14-2, # 14-9 #18-P													A									Note 1 TM:Allied-Kelite Products Div,. Chromate treatment for ferrous and non-ferrous metals.
Iridite™ #1, #2, #3, #4C, #4PC & S, #4P-4, #4-80, #4L-1, #4-2, #4-2A, #4-2P, #5P-1, #7-P, #8, #8-P, #8-2, #12-P, #15, #17P, #18P																			A			
Iridite™ Dyes-#12L-2, #40, #80																			A		A	Note 1
Irilac™																			A		A	Note 1 TM:Allied-Kelite Products Div., Protective coating, clear finish for all metals.

Hitco

Application Guide

Electric Heaters

Corrodant	Boiling Point B. P. °F	Auto Point F. P. °F	Auto Ignition A. I. °F	Iron Steel	Cast Iron Grey	Cast Iron NI Resist	Aluminum	Copper	Lead	Monel® 400	Nickel 200	304, 321, 347 Stainless Steel	316 Stainless Steel	Type 20 Stainless Steel	Inconoy® 800	Inconel® 600	Titanium	Hastelloy® B	Quartz	Graphite	Teflone®	Comments
Iron Fluoborate																				A	A	Note 1
Iron Phosphate (Parkerizing)				C		B						A	A									
Isoprep™ Deoxidizer #187, #188													A									Note 1 TM: Allied-Kelite Products Div., Cleaners and surface preparation materials.
Isoprep™ Acid Aluminum Cleaner #186													A									Note 1
Isoprep™ #191 Acid Salts																				A	A	Note 1
Isopropanol (Isopropyl Alcohol)	180	53	750	C			B	A		A	A	A	A/B	A		A		B		A	A	
Jetal™												A										Note 1 TM: Technic Inc. Blackening Salt
Kerosene	347 / 617	100 / 165	444	A			A	A	A	A	A	A	A	A	A	A	B	B		A	A	Note 2
Kolene™											A											TM: Metal Processing Co., Kolene process-metal cleaning
Lacquer Solvent				B	A	A	A	B	A	B	B	A	A	A	B	B	B		A			Note 2
Lead Acetate				X	X		X	X	X	A	A	A/B	A/B	A/B	A	A	A	B	A	A	A	
Lead Acid Salts												A										Note 1
Lime Saturated Water				B	B		X	B	X	B	B	B	A	B	B	B	B		X	A		
Linseed Oil	649	432	650	X	A		B	B	X	B	B	A	A	A	B	B	B	B	A	X	A	Note 2
		Raw																				
		403																				
		Boiled																				
Magnesium Chloride	2574			X	C	B	X	B	X	B	B	B	B	A/B	B	A	A	A	A	A	A	Carpenter 20 Accep. Hastelloy® C-276 Accep.
Magnesium Hydroxide				A	A	A	B	A	A	B	B	A	A	A	A	A	A	A	A	A	A	Hastelloy® C-276 Acceptable
Magnesium Nitrate				B	B		B	B	C	B	B	B	B	B	B	X	B	B	A	A	A	
Magnesium Sulfate				B	B	B	B	B	A	A	A	B	B	A/B	B	A	A/B		A	A	A	
MacDermid™ M629																				A	A	Note 1 TM: MacDermid, Inc., Acid
Mercuric Chloride																						Salt-Contains Fluoride
Mercury	579			X	X	X	X	X	X	X	X	X	B/X	X	X	X	B	X	A	A	A	
Methyl Alcohol (Methanol)	674			A	A	A	X	X	X	B	B	B	A	A	A	B	X	B	A	A	A	Hastelloy® C-276 Acceptable
Methyl Bromide	149	52	867	B	B		C	B	B	A	A	B	A/B	A/B	B	A	A	A	A	A	A	Note 2 Hastelloy® C-276 Acceptable
Methyl Chloride	38	None	998	C	C		X	B	B	B	B	A	A	A	B	B	A		A	A	A	
Methylene Chloride	-11	<32	1170	C	C		X	A	C	C	C	C	C	C	C	C	A	B	A	A	A	Carpenter 20 Acceptable
Mineral Oil	104		1224	X	C		C	C	B	C	B	C	B	A	C	B	A	C	A	A	A	Carpenter 20 Acceptable
Muriato		500		A	A		A/B	A	A	A	A	A	A/B	A	A	A	A	A	A	A	A	
Naptha																			A		A	Note 1
Nepthalene	300 / 421	100	900 / 950	A	B	B	A	A	A	A	A	A	A	A	A	A	A	B	A	A	A	
Nickel Acetate Seal	424	176	979	A	A	A	B	B	A	B	B	A	A	A	B	B	A	B		A	A	
													A								A	Note 1

Hitco

Application Guide

Electric Heaters

Corrodant	Boiling Point B. P. °F	Auto Point F.P. °F	Auto Ignition A. I. °F	Iron Steel	Cast Iron Grey	Cast Iron NI Resist	Aluminum	Copper	Lead	Monel® 400	Nickel 200	304, 321, 347 Stainless Steel	316 Stainless Steel	Type 20 Stainless Steel	Incoloy® 800	Inconel® 600	Titanium	Hastelloy® B	Quartz	Graphite	Teflon®	Comments
Nickel Chloride	1808			X	X	X	X	X	C	C	X	X	C	C	C	B	B	C	A	A	A	Notes 1, 5
Nickel Plate-Bright									A								A		A			Notes 1, 5
Nickel Plate-Dull									A										A			Notes 1, 5
Nickel Plate-Watts Solution																	A		A			Notes 1, 5
Nickel Sulfate				X	X	X	X	B	B	C	B	B	B	B	C	B	C	X	A	A	A	
Nickel Copper Strike (Cyanide Free)												A	A									Note 1
Nitric Acid	187			X	X	X	X	X	X	X	X	C	C	B	X	X	B	X	A	X	A	
Nitric Hydrochloric Acid				X	X		X	X	X	X	X	X	X	X	X	X	X		A	A	A	
Nitric 6% Phosphoric Acid													C						A			Note 1
Nitric Sodium Chromate													A						A			Note 1
Nitrobenzene	412	190		A	A	A	A	B	X	A	A	A	A	A	A	A	A	X	A	A	A	Note 2
Oakite™ #67												A										Note 1 TM: Oakite Products Inc. Compounds for cleaning surface heating.
Oakite™ #20, 23, 24, 30, 51, 90				A																		
Oleic Acid	680	372		C	C	C	C	C	X	B	B	C	B	A	B	A	B	B	A	A	A	Carpenter 20 Acceptable
Oxalic Acid				X	X	X	B	B	X	C	B	X	X	B	X	B	X	B	A	A	A	Cupro Nickel Acceptable
Paint Stripper (High Alkaline Type)				A																		Note 1
Paint Stripper (Solvent Type)													A									Notes 1, 2
Pafaffin				A	A		A	A		B		A	A	A				B		A	A	Notes 2, 7
parkerizing™ (See Iron Phosphate)																						
Perchloroethylene	250	None		B	B		C	B	B	A	A	B	B	B	B	A	A	B	A	A	A	
Perm-A-Chlor™ C												A										
Petroleum-Crude < 500°F				B	B	A	A	C	C	A	C	A	A	A					A	A		Notes 2, 3, 7
>500°F				A		A	A	X	X	X	X	A										
>100°F				X			X	X	X	X	X	A 347										
Phenol (See Carbolic Acid)																						
Phosphate													A									Notes 1, 5, 9
Phosphate Cleaner												A									X	Notes 1, 5, 9
Phosphatizing													A								X	Notes 1, 5, 9
Phosphoric Acid																						
Crude				C	X		X	X	C	X	X	C										
Pure < 45%				X	X	X	C	C	C	B	C	C	C	B	A	A	X	C		A	A	
>45% Cold				X	X	X	X	B	C	B	C	A	B	B	A		X	A		A	A	
>45% Hot				X	X	X	X	C	X	C	X	X	X	B	A	B	X	C		A	A	Tantalum Acceptable

Hitco

Application Guide

Electric Heaters

Corrodant	Boiling Point B. P. °F	Auto Point F. P. °F	Auto Ignition A. I. °F	Iron Steel	Cast Iron Grey	Cast Iron NI Resist	Aluminum	Copper	Lead	Monel® 400	Nickel 200	304, 321, 347 Stainless Steel	316 Stainless Steel	Type 20 Stainless Steel	Inconoy® 800	Inconel® 600	Titanium	Hastelloy® B	Quartz	Graphiite	Teflone®	Comments
Photo Fixing Bath										C		A										
Picric Acid	<572	302	572	X	X		X	X	X	X	X	B	B	B	C	C			A	A	A	
	Ex-																					
Potassium Acid Sulfate	Plodes																					
Potassium Bichromate																			A		A	Note 1
(Potassium Dichromate)				C	B	B	B		B	B	B	A	A	A	B		B	A	A	A	A	
Potassium Chloride												347										
Potassium Cyanide				C	X	B	X	C	C	B	B	C	B	A	C	B	A	C	A	A	A	Carpenter 20 Acceptable
Potassium Hydrochloric				C	X	B	X	X	X	C	B	B	B	B	B	B	X	B	A	C	A	
Potassium Hydroxide																			A		A	Note 1
Potassium Nitriate	2408			X	X		X	C	X	B	A	C	C	C	C	B	X	B	X	A	A	
(Salt Peter)																						
Potassium Sulfate				B	B	B	A	B	B	B	B	B	B	B	B	B	A	X	A	A	A	
Prestone™ 350oF				C	C	C	A	B	A	A	B	A	A	A	B	B	A	C	A	A	A	
				A						A												TM: Union Carbide Corp.,
R5 Bright Dip for Copper																						Anti-freeze/coolant
Polish at 180°F																						
Reynolds Brightener																						
Rhodium Hydroxide																			A		A	Note 1
Rochelle Salt Cyanide																			A		A	
Ruthenium Plating				A								A										Note 1
Sea Water																			A		A	Note 1
Silver Bromide				X	X	A	X	X	A	A		C	C	A	B	B	A	C	A	A	A	
Silver Cyanide				X	X		X	X		C	C	X	X	C			A		A	A	A	
Silver Lume				C	C		X	X		B		A	A	A	A		A	A	A	A	A	
Silver Nitrate												A										Note 1
Soap Solution	831			X	X		X	X	X	X	X	C	C	B	C	C	A	C	A	A	A	Hastelloy®C276 Acceptable
Sodium-Liquid Metal				A	A	A	X	C	A	A		A/B	A/B	A/B			A	B		A	A	Note 3
Sodium Bisulfate				C	C		X	X	X	B	A	A			A	A			X	X		
Sodium Bromide				X	X	X	C	B	C	C	B	X	X	A		B	C	B		A	A	Carpenter 20 Acceptable
SodSodium Carbonate	2534			B	C		X	B	B	B	B	C	B	B	B	B	B	C	A	A	A	
Sodium Chlorate				C	C		X	A	X	B	B	B	B	A	B	B	A	B	C	A	A	
Sodium Chlorate				X	X		B	A	B	A	A	B	B	B	B	A	A	X	A	A	A	Cupro-Nickel Acceptable
Sodium Chloride	2575			C	X	B	X	B	B	A	B	X	X	C	B	A	C	C	A	A	A	Cupro-Nickel Acceptable
Sodium Citrate				X	X		X	X	X		C	B	B	B			A	B	A	A	A	
Sodium Cyanide	2725			A	B	C	X	X	X	C	C	A	A	A	A	A	C	B	A	C	A	
Sodium Dichromate																						
(Sodium Bichromate)				B	B	B	C	X				B	B	B			C	X	A	A	A	
Sodium Disulfate				X	X		C		C	C	C	X	X	B		C	C		A	A	A	
Sodium Hydroxide																						
(See Caustic Soda)																						
Sodium Hypochlorite				X	X	X	X	X	X	X	X	X	X	B	X	X	A	A/X	A	C/A	A	Hastelloy® C276 Acceptable
Sodium Nitrate				B	B	A	C	C	C	B	B	A	A	A	A	A	A	C	A	A	A	
Sodium Peroxide				B	A	B	C	X	X	B	B	B	B	B		B		C			A	

Hitco

Application Guide

Electric Heaters

Corrodant	Boiling Point B. P. °F	Auto Point F. P. °F	Auto Ignition A. I. °F	Iron Steel	Cast Iron Grey	Cast Iron NI Resist	Aluminum	Copper	Lead	Monel® 400	Nickel 200	304, 321, 347 Stainless Steel	316 Stainless Steel	Type 20 Stainless Steel	Inconoy® 800	Inconel® 600	Titanium	Hastelloy® B	Quartz	Graphiite	Teflone®	Comments
Sodium Phosphate				C	C	B	X	B	B	A	C	B	A	B	B	A	A	B	A	A	A	
Sodium Salicylate				B	C	B		B		B	B	B	B	B	B	B			A	A	A	
Sodium Silicate				A	B	A	X	B	X	A	A	A	A	A	A	A	A	C	A	A	A	Note 4
Sodium Stannate				C	C	C				B	B	B	B	B	B	B			A		A	
Sodium Sulfate				B	C		C/B	B	B	B	B	C/X	A/B	B	B	B	C	B	A	A	A	
Sodium Sulfide				C	X	C	C	X	A	B	B	X	C	C	C	C	C	C	C	A	A	
Solder Bath				X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X	Note 4
Soybean Oil	540	833					B	A				A/B	B	B			A	A			A	
Stannostar™																			A		A	Note 1 TM:The Udylite Co., OMI Corp., Bright acid tin plating process.
Steam<500°F				A/B			A/B	A/B	C	A	A	A/B	B	B	A	A	B	A			A	
500-1000°F				C			C	C	X	C	C	A			A	A						
>1000°F				X			X	X		X	X	A			A	A						
Stearic Acid	721	385	743	C	C	C	C	X	X	B	B	C	A	A/B	B	B	B	A	A	A	A	Hastelloy® C-276 Acceptable
Sugar Solution				A	A		A	A	A	A	A	A	A	A	A	A	A		A	A	A	Note 7
Sulfamate Nickel																	A		A	A	A	Note 1
Sulfur	832	405	450	C	X	C	A	X	X	B	C	C	B	B	A	A	A	X	A	A	A	
Sulfur Chloride	280	245	453	X	X	C	X	X	B	X	C	C	X	C	C	B	X	B	A	X	A	
Sulfur Dioxide	14			C	C		C	C	B	X	X	C	B	B	C	C	A	X	A	A	A	
Sulfuric Acid	626																					
<10% Cold				X		X	C	A	B	B	C	X	C	B	C	X	X	A		A	A	
Hot				X	X	X	C	X	X	X	X	X	X	X	X	B	X	B		A	A	
10-75% Cold				X			X	B	B	C	C	X	X	B	B	X	X	A		A	A	
Hot				X			X	X	B	C	X	X	X	C	X	X	X	C		A	A	
75-95% Cold				B	B	B	X	B	B	X	X	B	B	B			X	C		A	A	
Hot				X	X	X	X	X	C	X	X	X	X	X			X	X		C	A	
Fuming				C	X	C	X	X	X	X	X	B	C	C	C	C		C				
Sulfurous Acid				X	X		C	X	A	X	X	X	C	B		C	A	B		A	A	
Tannic Acid		390	980	C	C		C/X	C	X	C	C	C	A	A	B	A	A	B	A	A	A	
Tar				A/B			A/B	B				A/B	B	B	A	A					A	
Tartaric Acid		410	802		X	B	C	X	C	B	C	C	A	B	A	B	B	B		A	A	
Tetrachlorethylene (See Perchloroethylene)																						
Thermoil Granodine™				B																		TM:Amchem Products, Inc. Chemical to produce anti-galling coatings.
Thermino™ FR1- Non Flowing				A																		TM: Monsanto Co., Heat transfer Fluid.
Tin (Molten)				B	B		X	X	X	X	X	B	B	X		X	A			X	X	Note 4
Tin-Nickel Plating																			A		A	Note 1
Tin Plating-Acid																				A	A	Note 1
Tin Plating-Alkaline				A								A										Note 1

Hitco

Application Guide

Electric Heaters

Corrodant	Boiling Point B. P. °F	Auto Point F. P. °F	Auto Ignition A. I. °F	Iron Steel	Cast Iron Grey	Cast Iron NI Resist	Aluminum	Copper	Lead	Monel® 400	Nickel 200	304, 321, 347 Stainless Steel	316 Stainless Steel	Type 20 Stainless Steel	Inconoy® 800	Inconel® 600	Titanium	Hastelloy® B	Quartz	Graphite	Teflone®	Comments
Toluene	231	40	947	A	A	A	A	C	A	A	A	A	A	A	A	A	A	A		A	A	Hastelly® C-276 Acceptable
Triad Solvent				C																		
Trichloroethane				A	C	C	B	B	B	B	B	A	B	B	B	B	A		A	A		
Trichloroethylene	165	None		B	C	C	B	C	X	C	C	B	B	B	B	A	A	A	A	A	A	Hastelly® C-276 Acceptable
Triethylene Glycol	556	350	700	A	A	A	A	A	A	A	A	A	A	A	A	A	A		A			
Trioxide (Pickle)																			A		A	Note 1
Trisodium Phosphate				A	A		X	C	X	C	C	C	C	C				C	X	B	X	
Turco™ 2623				A																		TM: Turco Products, Div., Purex Corp., Ltd.
Turco™ 4008, 4181,4338													A									Note 1
Turco™ Ultrasonic Solution													A									Note 1
Turpentine Oil	309 -338	95	488	C	C	C	A	B	A	A	A	A	A	A		A	B	B		A	A	
Ubac™ Uk																			A			Note 1 TM: The Udylite Co., OMI Corp., High leveling acid copper bath.
Udylite #66																	A		A		A	Note 1, 5
Unichrome™ CR-110																			A		A	Note 1 TM: M & T Chemicals Inc., Plating Process, supplies and equipment.
Unichrome™ 5RHS																			A		A	Note 1
Uegetable Oil	610	610		C			B	X	X	A	A	A	A	A	A		A	B		A	A	
Vinegar				C			C			A		B	A/B	B			A	B		A	A	
Water (Fresh)				X	C	A	A	A	A	A	A	C	C	A	A	A	A		A	A		
Water (Deionized) (See Deionized Water)																						
Water (Sea) (See Sea Water)																						
Watt's Nickel Strike																			A			Note 1
Whiskey and Wines				X		C		A		A	A	A	A	A	A	A	A	A		A	A	
Wood's NickelStrike																			A			Note 1
Yellow Dichromate													A						A			Note 1
X-Ray Solution												A	A									
Zinc (Molten)	1664						X	X	X	X	X	X	X	X	X	X	X				X	
Zinc Chloride	1350			C	C	C	X	X	B	B	B	X	X	B	X	B	C	B	A	A	A	
Zine Phosphate													A								X	Notes 1, 5
Zinc Plating Acid																			A			
Zinc Plating Cyanide				A								A										Note 1
Zinc Sulfate				C	X	A	C	B	A	B	C	C	C	C		B	A	C		A	A	
Zincate™				A								A										Note 1 TM: Ashland Chemical, Alkaline Salt for immersion zinc plating alumium.

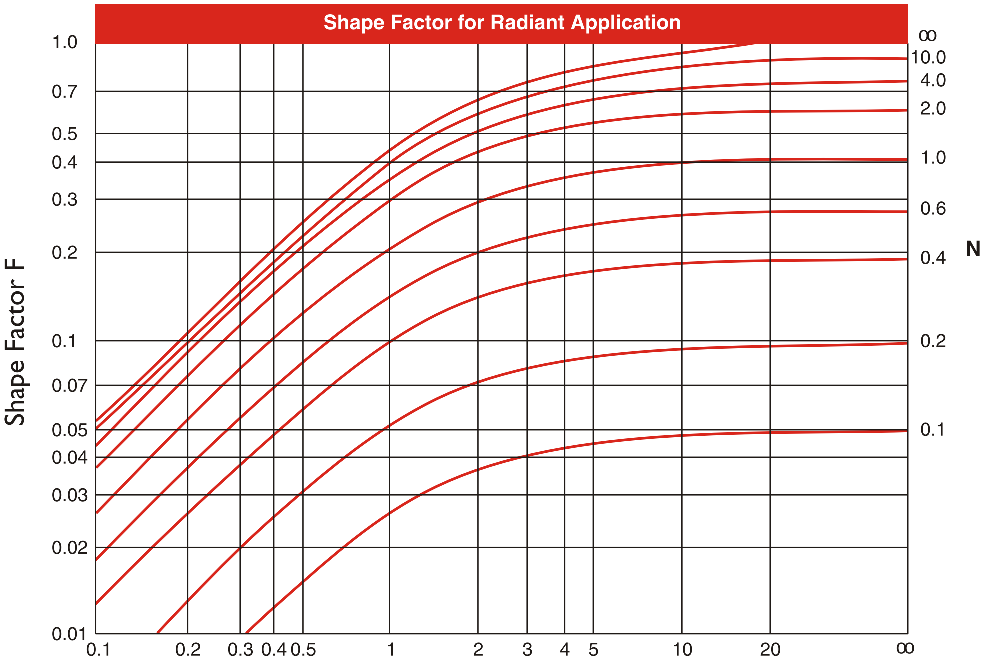
Hitco

Application Guide

Electric Heaters

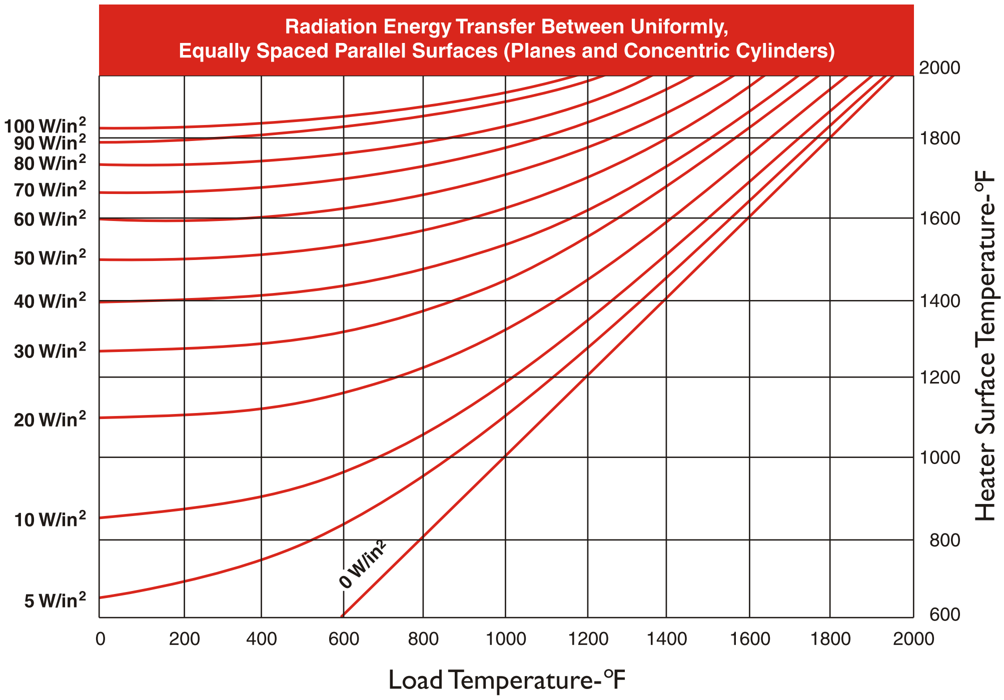
Energy Calculations

Ref. 139



For Two Facing Panels: $N = \left(\frac{\text{Heated Length}}{\text{Distance to Material}}\right)$ **M** $= \left(\frac{\text{Heated Length}}{\text{Distance to Material}}\right)$

Ref. 140



Application Guide

Electric Heaters

Examples of Applications

Objective

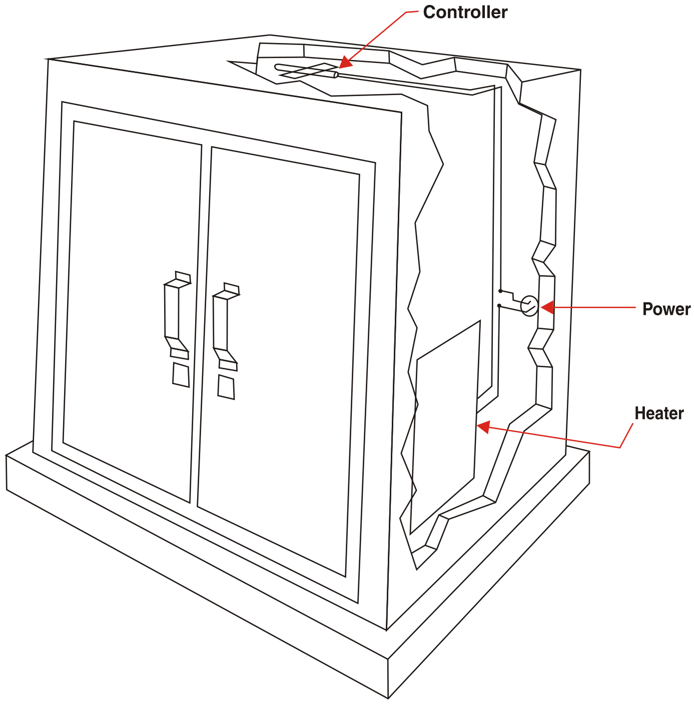
An insulated steel cabinet located outdoors on a concrete pad contains an electronic control system for outdoor signaling equipment. The cabinet is three feet wide, two feet deep and four feet high with a two-inch thickness of insulation applied to the outer surfaces. Under the worst conditions the cabinet is exposed to temperatures of -200F and 20 MPH winds. The objec-tive is to provide heating to maintain the electrical equipment above the freezing temperature. The control system normally consumes 75 watts of power but must be protected even when not in operation. A terminal strip within the cabinet provides 120 volt, singlephase power.

Power Requirements

For this application, we only need to be concerned with how much power is required to make up the cabinet's heat losses. The heat losses are continuous assuming a worst case situation (-200F and 20 mph winds).

Cabinet Freeze Protection

Ref. 141



Determine Thermal System Heat Losses

a. Conduction. Heat losses through the concrete base are negligible using Equation 3A, (Page 17).

b. Combined convection and radiation-losses from exposed surfaces-From Equation 3D, (Page 18).

Q_{L4} = A · F_{SL} · t_e

= (6624 in^2) · (0.03 W/in^2) · (2.75) · (1 hr)

Q_L = 546 Wh

where:

A = the exposed surface area

= 2 ft · 3 ft + 2 · (3ft .4 ft) + 2 · (2 ft .4ft) = 46 ft2

= 6624 in^2

ΔT = temperature difference = 320F - (-200F)

= 52°F

F_{SL} = the heat loss coefficient for 2 inch insulation at ΔT= 52°F from Ref. 12, page 28 = 0.03 W/in2 multiplied by the wind velocity correction factor at 20 mph (2.75 from Ref. 16, Page 29). Since Ref. 12, Page 28 is baed on 70°F ambient rather than - 20°F, find the coefficient at an equivalent temperature of 122°F

t_e = the exposure time = 1 hour

Application Guide
Electric Heaters

Examples of Applications
Continued

Calculate Operating Power Requirments
From Equation 5, (Page 18) using a 10 percent safety factor,

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

$$= \frac{546\ Wh}{1\ hr} \cdot 1.1 = 601\ W$$

where :

QB = 0

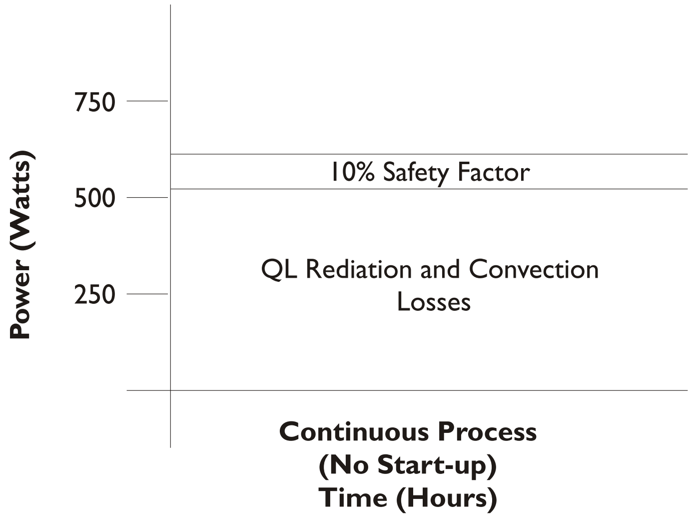
QD = 0

QL = 546 Wh

tc = assume 1 hour

te = 1 hour

Cabinet Freeze Protection Power Evaluation
Ref. 142



Heater Recommendation

A flexible silicone rubber heater six inch X 20 inch rated at 600 watts, 120 volts mounted near the bottom of the cabinet provides a simple and inexpensive solution for enclosure heating. The heater may be ordered with a pressure sensitive adhesive surface for easy mounting.

Control

This application requires only very simple control to ensure the insulated steel cabinet maintains a preset temperature above freezing. A Hitco basic controller preset to 400F will protect the cabinet above the freezing point.

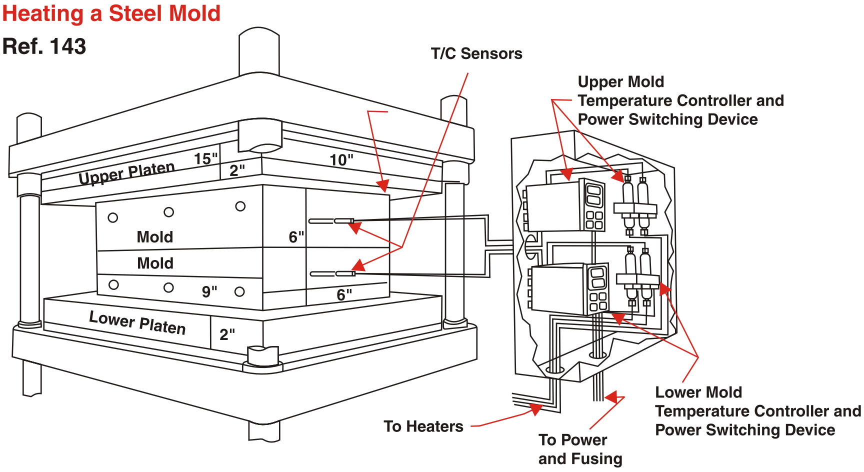
Application Guide
Electric Heaters

Examples of Applications
Continued

Objective
A mild steel compression mold is used to form plastic parts.Twoounce charges of plastic at room temperature are inserted at a rate of 30 per hou. The steel mold is six inch X nine inch X six inch overall and is placed between two steel platens. each 10 inch X 15 inch X two inch.The platens are insulated from the press with 1/2 inch thick rigid insulation board.The mold must be pre-heated to 3500F in 45 minutes while closed. Room temperature is 700F.

Power Requirements
The following steps illustrate the calculations to estimat3e the power in watts needed for initial heating and to maintain the operating temperature.

Heating a Steel Mold
Ref. 143



Step 1 : Initial Heating of the Mold and Platens
From Equation 1, (Page 16)

$$Q^A = \frac{W \cdot C_P \cdot \Delta T}{3.412}$$

$$= \frac{(263 \text{ lbs}) \cdot (0.12 \text{ Btu/lb} \cdot {}^\circ\text{F}) \cdot (280^\circ\text{F})}{3.412 \text{ Btu/Wh}}$$

$$= 2590 \text{ Wh}$$

Where :

W = weight to mold and platens
= volume (in^3) X density (lbs/in^3)
= [(6 in. • 9 in. • 6 in.) + (10 in. • 15 in. • 2 in.)] (0.284 lbs/in^3)
= 263 lbs

Cp = specific heat of steel = 0.12 Btu/lb • °F

ΔT = temperature rise = 350°F - 750°F = 280°F

Hitco

Application Guide

Electric Heaters

Examples of Applications

Continued

Step 2: Heating of Plastic During the Operating Cycle

From Equation 1, (Page 16).

$$QB = \frac{(0.125 \text{ lbs}) \cdot (0.4 \text{ Btu/lb} \cdot {}^\circ\text{F}) \cdot (280^\circ\text{F})}{3.412 \text{ Btu/Wh}}$$

$$= 4.1 \text{ Wh}$$

where :

w = weight of plastic charge = 2 oz. = 0.125 lb

Cp = specific heat of plastic = 0.4 Btu/lb . °F

ΔT = temperature rise = 280 °F

Step 3: Heat Required to Melt or Vaporize Materials During Initial Heating

Not required since plastic is not present during initial heat-up.

$Q_c = 0$

Step 4: Heat Required to Melt or Vaporize Materials During the Operating Cycle

Not required since the plsatic does not change phase during the molding operation.

$Q_D = 0$

Step 5: Determine Thermal System Heat Losses

Energy is required to replace heat lost to conduction, convection and radiation:

a. Conduction losses through the insulated surfaces

From Equation 3A, (Page 17).

$$QL1 = \frac{K \cdot A \cdot \Delta T \cdot t_e}{3.412 \cdot L}$$

$$= \frac{(5.2 \text{ Btu} \cdot \text{in./ft}^2 \cdot {}^\circ\text{F . hr}) \cdot (2.08 \cdot \text{ft}^2) \cdot (2800^\circ\text{F}) \cdot (1 \text{ hr})}{(3.412 \text{ Btu/Wh}) \cdot (0.5 \text{ in.})}$$

$$= 1775 \text{ Wh}$$

where :

K = the thermal conductivity of 1/2 inch rigid insulation board
= 5.2 Btu • inch/hr • ft² • °F

A = The total insulated surface area

$$= \frac{2 . (10 . 15) \text{ in2}}{144 \text{ in/1ft2}} = 2.08 \text{ ft}^2$$

ΔT = the temperature differential between the heated platen and the outside insulation at ambient = 350°F - 70°F = 280°F

L = the insulation thickness = 0.5 inch

t_e = exposure time = 1 hour

Application Guide

Electric Heaters

Examples of Applications

Continued

b. Convection losses

From Equation 3B, (Page 17)

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

Sides :

Q_{L2} = $(180\ in^2 + 200\ in^2) \cdot (0.64\ W/in^2) \cdot (1\ hr)$
= 243 Wh

where :

F_{SL} = the surface loss factor for a vertical surface at 350°F is 0.64 W/in^2 from Reference 9, (Page 26)

A_1 = mold side area = 2 • (6 in. • 6 in.) = 2 - (6 in. • 9 in.)
= 180 in^2

A_2 = platen side area = 4 • (2 in. • 10 in.) + 4 • (2 in. • 15 in.)
= 200 in^2

C_F = correction factor = 1.0

t_e = exposure time = 1 hr

Bottom (of the top platen):

QL = (96 in2) . (0.64 W/in2) . (0.63) . (1 hr)
= 39 Wh

where :

A = exposed platen area = (10 in. • 15 in.) - (6 in. • 9 in.)
= 96 in^2

F_{SL} = 0.64 W/in^2

C_F = the correction factor for bottom surfaces (0.63 from Reference 9, page 26)

t_e = exposure time = 1 hr

Top (of the bottom platen):

Q_L = $(96\ in^2) \cdot (0.64\ W/in^2) \cdot (1.29) \cdot (1\ hr)$
= 79 Wh

where :

C_F = the correction factor for top surfaces (1.29 from Reference 9, Page 26)

Application Guide

Electric Heaters

Examples of Applications
Continued

c. Radiation losses

From Equation 3C, (Page 17)

Q_{L3} = $A \cdot F_{SL} \cdot e \cdot t_e$
= $(572\ in^2) \cdot (1.3\ W/in^2) \cdot (0.75) \cdot (1\ hr)$
= 558 Wh

where:

A = the total surface area of mold sides, platen sides and exposed platen top and bottom is 572 in^2

F_{SL} = the blackbody radiation loss factor at 350°F is 1.3 W/in^2 from Reference 9 (Page 26)

e = the emissivity of mild steel with a medium oxide finish (0.75 from Reference 10 (Page 27)

t_e = exposure time = 1 hr

d. Total heat losses

From Equation 3E, (Page 18)

Conduction	1775 Wh
Convection-sides	243
Convection-bottom	39
Convection-top	79
Radiation	558
Total Q_L	2694 Wh

Step 6 : Calcutate Start-Up Power Requirements

Start-up power is required for initial heating of the mold and platens. to compensate for losses during start-up plus a 10 percent safety factor.

From Equation 4, (Page 18)

$$\text{Start-up Power} = \left[\frac{Q_A + Q_C}{t_s} + \frac{2}{3} \left(\frac{Q_L}{t_e} \right) \right] \cdot (1 + S.F.)$$

$$= \left[\left(\frac{2590\ Wh}{0.75\ hr} \right) + \frac{2}{3} \left(\frac{2694\ Wh}{1\ hr} \right) \right] . (1.1)$$

$$= 5774 \text{ watts}$$

where :

Q_A = initial heating of mold and platens
= 2590 Wh

Q_C = latent heat = 0

Q_L = heat losses = 2694 Wh

t_s = start-up time = 0.75 hours

t_e = exposure time for losses = 1 hr

S.F. = safety factor = 10%

Application Guide

Electric Heaters

Examples of Applications
Continued

Step 7 : Calculate Operating Power Requirements
Operating Power is required to heat each plastic charge and to compensate for operating losses. From Equation 5, (Page 18) using a 10 percent safety factor,

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

$$= \left[\left(\frac{4.1\ Wh}{0.0333\ hrs}\right) + \left(\frac{2694\ Wh}{1\ hr}\right)\right] \cdot (1.1)$$

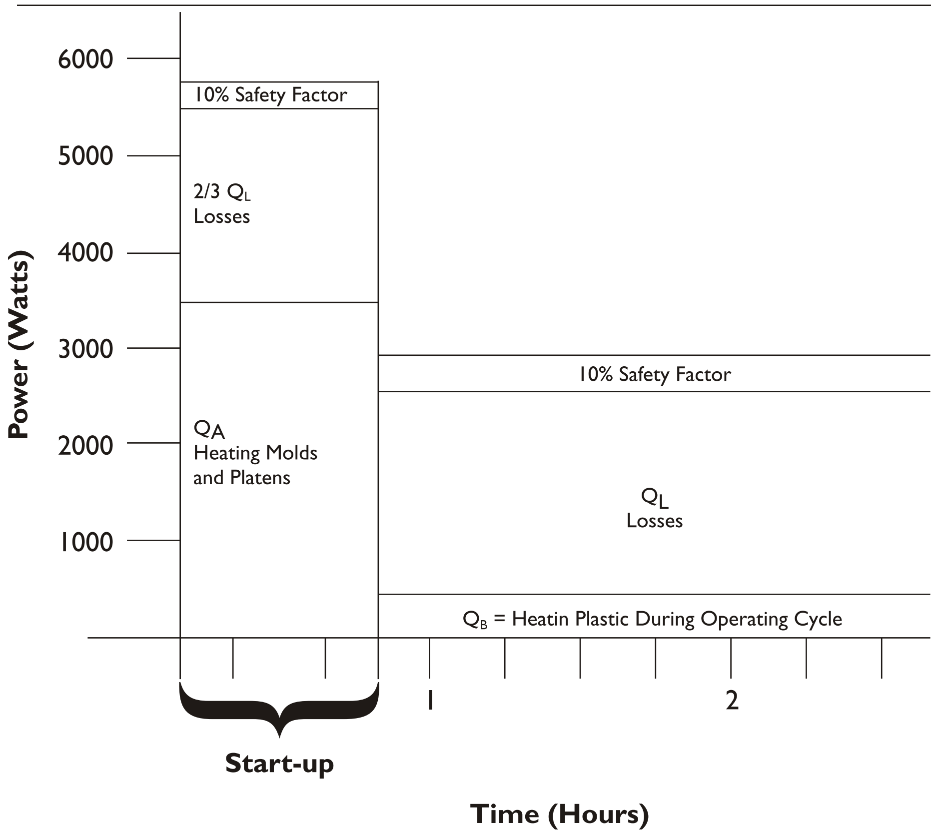
$$= 3099\ \text{watts}$$

where:

Q_B = Heating of plastic during operation = 4.1 Wh
Q_D = Latent Heat = 0
Q_L = Heat losses = 2694 Wh
t_c = Cycle time at 30 charges per hour = 0.0333 hrs
t_e = Exposure time for losses = 1hr
S.F. = Safety Factor = 10%

Heating a Steel Mold Power Evaluation

Ref. 144



Hitco

Application Guide

Electric Heaters

Examples of Applications

Continued

Heater Recommendation

Heating capacity is determined by either the start-up power requirement or the operating power needed, whichever is larger. In this case, a minimum of 5700 watts is required.

Heater selection is dictated by a number of factors including efficiency, even heat distribution, watt density and availability.

Since heating efficiency is optimized by heating the mold from within, six cartridge heaters inserted into holes drilled in the molds are recommended. The heaters are stock 1/2 inch diameter X six inch length FIREROD® HEATERS RATED 1000 WATTS AT 240 volts. Three heaters each in the top and bottom molds should be arranged to surround the cavity. Holes will be drilled completely through the mold to facilitate heater removal.

Hole Fit and Watt Density

A normal tolerance for a ½ inch drilled hole is ±o.oo5 inch and the diameter of a standard ½ inch FIREROD cartridge heater is slightly undersized at 0.496 inch ±0.002 inch. Therefore the worst-case clearance or "fit" is 0.011 inch (0.505 - 0.494 inch).

Assuming close temperature control with frequent on-of cycling of the heater, the maximum watt density should be derated to 126 W/in² using a 0.7 multiplier. The recommended ½ inch X six inch, 1000 watt heaters are rated at 117 W/in² which is within the maximum of 126 W/in² for this application. Therefore the heaters are conservatively rated and should yield extended life.

Environmental Factors

The biggest single cause of heater failure is contamination. This contamination can come from many sources such as lubricating oil, cleaning solvents, plastic material or fumes, organic tapes, etc. As a heater cools down, it "inhales" these contaminates. Upon reaching the heated zone, the contaminates carbonize causing electrical arcing and failure.

The heaters may be specified with a teflon® seal or with silicone rubber potting in the lead end of the heater to protect against contamination, Both are effective at 400°F. For higher temperature applications MI lead assemblies are available.

In addition, stainless steel hose, stainless steel braid or galvanized BX conduit may be ordered with the heaters to protect the leads against abrasion. Either right angle or straight terminations are available for wiring convenience.

Control

The heaters may be controlled individually, or as a group, depending on the need for precision in temperature and heat distribution. The Plastic molding material itself and the configuration of the molded part will dictate the level of the molded part will dictate the level of temperature precision and heat distribution precision necessary. A Type J thermocouple is used as standard sensor for plastics molding. This application demands narrow temperature control. Two PID temperature controllers, one for the top and one for the bottom, plus a separate power switching device for each, will do the job. The Hitco SERIES SD with a DIN-A-MITE® power controller is the recommended control solution. The SERIES SD offers autotuning or manually-Set PID values, as well as a configurable alarm output. Two SERIES SDs. with switched DC output, in conjunction with two Hitco DIN-A-MITE controllers control the heaters.

Hitco

Application Guide

Electric Heaters

Examples of Applications

Continued

Objective

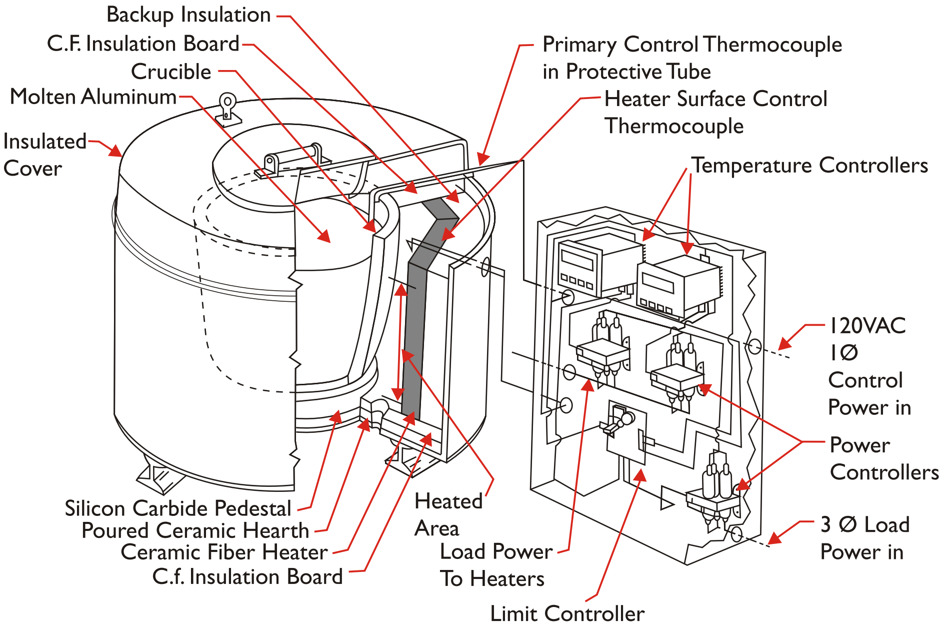
Design a furnace to melt at least 250 lbs of aluminum ingots per hour and raise the crucible, furnace and aluminum to a working temperature of 1350°F in five hours using ceramic fiber heaters. The aluminum is held in a 1000 lb capacity silicon carbide crucible. The crucible is 26 inches in diameter at the top, 18 inches in diameter at the top, 18 inches in diameter at the bottom and 24 inches in height. Will thickness is two inches. The crucible rests on oa silicon carbide pedestal four inches thick. The crucible and pedestal together weight 300 lbs. Ambient temperature is 70°F.

Furnace Construction

The inside diameter of the furnace should be 30 inches, that is, an air gap between furnace wall and crucible of two inches, or four inches larger than the crucible diameter. Ceramic fiber heaters include two inch thick insulation and are surrounded by four inches of additional back-up insulation. The overall diameter is 42 inches. Total furnace height is 34 inches allowing 24 inches for the crucible, for inches for the pedestal. two inches for a hearth and four inches for the cover. Approximately 20 cubic feet of insulating material is included. The chassis shell is constructed of 1/8 inch thick steel.

Power Requirements

The following steps illustrate how to calculate the power in



Step 1: Initial Heating and Melting of Aluminum, Initial Heating of Crucible and Furnace

a. Aluminum from ambient to 1080F, the melting temperature of a typical aluminum alloy
using Equation 1, (Page 16)

$$QA = \frac{W \cdot C_P \cdot \Delta T}{3.412}$$

$$= \frac{(1000 \text{ lbs}) \cdot (0.24 \text{ Btu/lb} \cdot {}^\circ F) \cdot (1010^\circ F)}{3.412 \text{ Btu Wh}}$$

$$= 71{,}043 \text{ Wh}$$

where:

W = aluminum weight = 1000 lbs

C_P = specific heat of solid aluminum
= 0.24 Btu/lb • °F

ΔT = temperature rise = 1080°F - 70°F = 1010°F

Examples of Applications
Continued

b. Heat required to melt the aluminum during start-up
From Equation 2, (Page 16)

$$QC = \frac{W \cdot H_f}{3.412}$$

$$= \frac{(1000 \text{ lbs}) \cdot (167 \text{ Btu/lb})}{3.412 \text{ Btu/Wh}}$$

$$= 48{,}945 \text{ Wh}$$

where:
w = weight of aluminum = 1000 lbs
H_f = aluminum heat of fusion = 167 Btu/lb

c. Aluminum from 10800F to the casting temperature of 13500F

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

$$= \frac{(1000 \text{ lbs}) \cdot (0.26 \text{ Btu/lb} \cdot {}^\circ F) \cdot (270^\circ F)}{3.412 \text{ Btu/Wh}}$$

$$= 20{,}574 \text{ Wh}$$

where :
w = weight of aluminum = 1000 lbs
ΔT = 1350°F - 1080°F = 270°F
C_p = 0.26 Btu/lb • °F for molten aluminum

d. Crucible and pedestal

$$Q_A = \frac{(300 \text{ lbs}) \cdot (0.19 \text{ Btu/lb} \cdot {}^\circ F) \cdot (1380^\circ F)}{3.412 \text{ Btu/Wh}}$$

$$= 20{,}054 \text{ Wh}$$

where :
W = weight of crucible and pedestal = 300 lbs
C_p = specific heat of silicon carbide used
= 0.19 Btu/lb . °F
ΔT = 1450°F - 70°F = 1380°F (From experience, the average crucible temperature will be about 100°F hotter than he molten aluminum)

Hitco

Application Guide

Electric Heaters

Examples of Applications

Continued

e. Insulation

$$Q_A = \frac{W \cdot C_P \cdot \left(\frac{T_1 + T_2}{2}\right) - 70^\circ}{3.412}$$

$$= \frac{(300 \text{ lbs}) \cdot (0.27 \text{ Btu/lb} \cdot {}^\circ F) \cdot (880^\circ F)}{3.412 \text{ Btu/Wh}}$$

$$= 20{,}891 \text{ Wh}$$

where :

density of ceramic fiber insulation = 15 lbs/ft^3

w = weight of insulation = volume • density

= 20 ft^3 • 15 lbs/ft^3 • 300 lbs

C_P = specific heat of insulation = 0.27 Btu/lb • °F

= approx. 1700°F from experience. The actual heater temperature is calculated in later paragraphs.

T_2 = Chassis temperature = 200°F From "Insulation Effectiveness" on page 146 of the Hitco Heaters catalog. Use the graph at 1700°F heater temperature and 6 inch insulation.

T_A = average insulation temperature

$$= \frac{T_1+T_2}{2} = 950^\circ F$$

ΔT = average temperature rise

= T_A - 70°F = 880°F

f. Chassis and structure

$$Q_A = \frac{(258 \text{lbs} + 200 \text{ lbs}) \cdot (0.122 \text{ Btu/lb} \cdot {}^\circ F) \cdot (130^\circ F)}{3.412 \text{ Btu/Wh}}$$

$$= 2129 \text{ Wh}$$

where :

density of steel = 490 lbs/ft^2 = 0.284 $lbs.in^3$

w_1 = weight of steel chassis shell

= surface area • thickness • density

= (7257 in^2) • (0.125 in.) • (0.284 lbs/in^3)

= 258 lbs

w_2 = weight of additional steel supports, brackets, mounting pads

= 200 lbs (assume)

C_P = Specific Heat of steel used = 0.122 Btu/lb • F

ΔT = temperature rise = 200°F - 70°F = 130°F

Examples of Applications
Continued

g. Total for initial heating

aluminum to 1080°F	=	71,043 Wh
aluminum from 1080°F to 1350°F	=	20,574 Wh
crucible and pedestal	=	23,054 Wh
insulation	=	20,891 Wh
chassis and structure	=	2,129Wh
Total Q_A	=	137,691 Wh
Total Q_C	=	48,945 Wh

Step 2: Heating and Melting of Aluminum During Operating Cycle

a. Heat aluminum to the melting point
From Equation 1, (Page 16).

$$Q_B = \frac{w \cdot C_P \cdot \Delta T}{3.412}$$

$$= \frac{(250\ \text{lbs}) \cdot (0.24\ \text{Btu/lb} \cdot {}^\circ\text{F}) \cdot (780^\circ\text{F})}{3.412\ \text{Btu/Wh}}$$

$$= 13{,}716\ \text{Wh}$$

where:
W = 250 lbs of aluminum ingots
ΔT = 1080°F - 300°F. Aluminum ingots are preheated to 300°F to eliminate moisture on the aluminum ingots.

b. Heat required to melt the aluminum during the operating cycle
From Equation 2, (Page 16).

$$QD = \frac{W \cdot Hf}{3.412}$$

$$= \frac{(250\ \text{lbs}) \cdot (167\ \text{Btu/lb})}{3.412\ \text{Btu/lb}}$$

$$= 12{,}236\ \text{Wh}$$

c. Heat aluminum from melting point to operating temperature
From Equation 1, (Page 16).

$$QB = \frac{W \cdot C_P \cdot \Delta T}{3.412}$$

$$= \frac{(250\ \text{lbs}) \cdot (0.26\ \text{Btu/lb} \cdot {}^\circ\text{F}) \cdot (270^\circ\text{F})}{3.412\ \text{Btu/Wh}}$$

$$= 5{,}144\ \text{Wh}$$

d. Total for operating cycle
Q_B = 13,716 + 5,144 = 18,860 Wh
Q_D = 12,236 Wh

Examples of Applications
Continued

Step 3: Determine Thermal System Heat Losses

Power is required to replace heat energy lost from the surfaces of the furnace by convection and radiation. Using Equation 3D, (Page 18).

a. Side losses

Experience has shown that during long melting cycles, the internal heater wire temperature rises, which in turn raises the side surface temperatures of the furnace.

Q_{L4} = $A \cdot F_{SL} \cdot t_e$
= $(4486\ in^2) \cdot (1.0\ W/in^2) \cdot (1\ hr)$
= 4486 Wh

where:

A = side surface area = 42 in. dia . π . 34 in. height
= 4486 in^2
F_{SL} = surface loss factor for the chassis at 260°F (an increase of 60°F during melting)
= 1.0 W/in^2
t_e = exposure time for losses = 1 hr

b. Top losses

Q_{L4} = $A \cdot F_{SL} \cdot C_F \cdot t_e$
= $(1385\ in^2) \cdot (0.4\ W/in^2) \cdot (1.29) \cdot (1\ hr)$
= 715 Wh

where :

A = top surface area = $(42.2\ in\ .\ dia/2)^2\ .\ \pi$
= 1385 in^2
F_{SL} = surface loss factor for the top surface at 170°F (170°F from page 146 of the Hitco Heater's catalog for an inside surface temperature of 1350°F and four inch insulation.)
= 0.4 W/in^2 (Ref. 9, see Page 26 for oxidized steel)
C_F = top surface correction factor of 1.29

t_e = exposure time for losses = 1 hr

Application Guide

Electric Heaters

Examples of Applications
Continued

c. Bottom losses

Q_{L4} = $A \cdot F_{SL} \cdot C_F \cdot t_e$
= (1385 in^2) · (0.95 W/in^2) · (0.63) · (1 hr)
= 829 Wh

where :
A = 1385 in^2 (previously calculated)
F_{SL} = Surface loss factor for a surface at 250°F
(bottom temperature = 250°F; assume hotter than top or sides due to pedestal and poured ceramic hearth)
= 0.95 W/in^2
C_F = bottom surface correction factor of 0.63
t_e = exposure time for losses = 1 hr

d. Open furnace cover losses

Opening and closing of the furnace cover to add additional ingots, causes significant power losses. The 22 inch diameter skin of the molten aluminum in a full crucible, the upper edges of the exposed crucible and other surfaces are all sources of heat losses when the cover is open. Assuming the cover is opened and closed several times per hour, we can say that the cover is open for 10 minutes during a one hour period. From Equation 3D, (Page 18).

Q_{L4} = $A \cdot F_{SL} \cdot t_e$
= (380 in^2) · (13 W/in^2) · (0.167 hr)
= 825 Wh

where :
A = molten aluminum surface area
= $(22 \text{ in. dia}/2)^2 \cdot \pi$
= 380 in^2
F_{SL} = surface loss factor from Reference 13 (Page 28) at 1080°F
= 13 in^2
t_e = 10 minutes = 0.167 hr

e. Total losses

Sides	=	4486 . Wh
Top	=	715 . Wh
Bottom	=	829 . Wh
Open Lid	=	825 . Wh
Total Q_L	=	6855 . Wh

Application Guide

Electric Heaters

Examples of Applications
Continued

Heater Recommendation

Twelve standard eight inch X 24 inch high watt density, flat ceramic fiber heaters arranged in a circle around the crucible will form an inside diameter of about 30 inches. Each eight inch X 24 inch heater with sinuated wire elements is rated at 3600 watts with furnace hot face temperatures up to 1800°F. Twelve heaters will produce 43,200 watts.

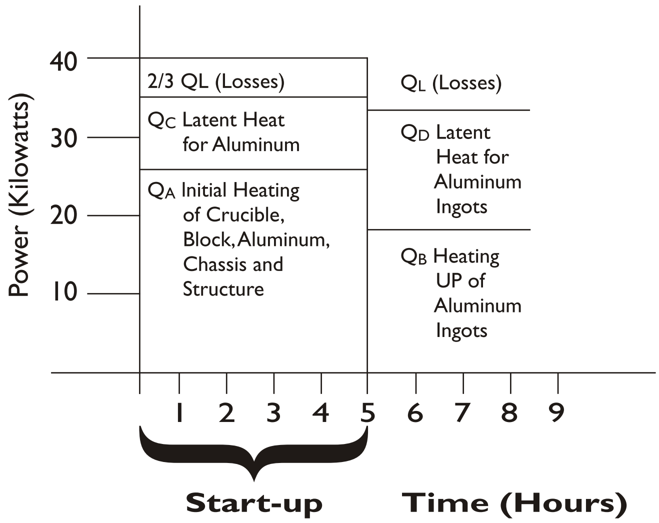
Heater Performance Limits Verification

It is necessary to verify the element operating temperature and insure that the load can absorb the energy produced by the heaters fast enough to prevent heater damage.

First, use the heat transfer equation for thermal conductivity through the crucible to calculate the outside surface temperature of the crucible. Then use the radiant heat transfer equation to calculate the heater element temperature.

Note that the thermal conductivity of new silicon carbide is reasonably good at K = 112. however, as the crucible ages, thermal conductivity can decrease drastically to as little as 20 percent of original value. A 50 percent decrease in the thermal conductivity will cause the ΔT across the crucible to double, simply to conduct the same amount of heat. This must be considered when designing the furnace and its control system.

Melting of Aluminum Power Evaluation
Ref. 146



Crucible Surface Temperature

From Equation 3A, (Page 17) heat energy conducted through the crucible:

$$Q = \frac{K \cdot A \cdot T_{\Delta} \cdot t_e}{3.412 \cdot L}$$

Solve for $T\Delta$

$$\Delta T = \frac{Q}{t_e} \cdot \frac{3.412 \cdot L}{K \cdot A} = T_1 - T_2$$

$$= \frac{(35{,}445\ W) \cdot (3.412\ Btu/Wh) \cdot (2\ in.)}{(112\ Btu \cdot in./hr \cdot ft^2 \,.\, {}^\circ F) \cdot (13.5\ ft^2)} = 160^\circ F$$

Then $T_1 = T_2 + \Delta T = 1510^\circ F$

where :

$\frac{Q}{t_e}$ = power available to melt the aluminum. This is calculated by subtracting heat losses during operation from the rated power of the heaters.
= 42,300-6855=35,445 W

L = crucible thickness = 2 in.

K = thermal conductivity of silicon carbide
= 112 Btu - in./hr - ft^2 - °F (From Reg. 132, Page 134)

A = crucible surface temperature

T_1 = crucible outside surface temperature

T_2 = crucible inside surface temperature = 1350°F

Hitco

Application Guide

Electric Heaters

Examples of Applications

Continued

Since the equation was originally written for equal size parallel plates, and we are dealing essentially with concentric cylinders, the proportional differences between the different diameters must be factored into the analysis. The ratio (R) takes this into account when the outer cylinder (the heater, or source) radiates heat toward the inner cylinder (the load) . The shape factor (F) is assumed to be one as end effects are negligible near the center of the crucible's height.

The best heat transfer condition occurs where there are small differences in the shape/size of the source and load. Where the differences are large, the temperature of the source must be significantly higher to transfer the same amount of heat energy.

For this crucible application, the best heat transfer condition occurs where the crucible diameter is largest. te Similarly, the heat transfer near the bottom of bowl shaped crucibles is poorest. Generally, design should be bassed upon the worst case condition however, for this example, we can ignore this situation, since convection effects cause the heat to rise from the bottom of the bowl area thus equaling the flow between heater and crucible.

Heater Surface Temperature

From Equation 6, (Page 19) the heat energy radiated from the heater to the crucible:

$$\text{Watt Density (W/in2)} = \frac{Q}{t_e \cdot A} = \frac{S \cdot (T_2^4 - T_2^4) \cdot \left(\frac{1}{\frac{1}{e_1} + \frac{1}{e_2} - 1} \right) \cdot F}{144.3.412}$$

For concentric cylinders, this equation becomes:

$$\text{Power (watts)} = \frac{Q}{te} = \frac{S \cdot A \cdot (T_1^4 - T_2^4) \cdot \left(\frac{1}{\frac{1}{e_1} + R \cdot \frac{1}{e_2} - 1} \right)}{144.3.412}$$

Now, solving for the heater element temperature T1:

$$T_1^4 = T_2^4 = + \frac{Q \cdot (144) \cdot (3.412)}{t_e \cdot S \cdot A} \cdot \left(\frac{1}{e_1} + R \cdot \frac{1}{e_2} - 1 \right)$$

T1 = 2146°R = 1686°F

where:

Q = power radiated to the crucible = 35,445 watts

S = Stefan-Boltzman constant

= 0.1714×10^{-8} Btu/hr . ft^2 . $°R^4$

T_1 = heating element temperature

T_2 = crucible outside surface temperature

= 1510°F = 1970°R

e_1 = heater emissivity = 0.88

e_2 = silicon carbide crucible emissivity = 0.92

D_1 = heater diameter = 30 in.

D_2 = crucible diameter = 26 in.

$$R = \frac{D_1}{D_2} = \frac{30}{26} = 1.1538$$

A = heater surface area = 12 • 8 in. • 24 in.

= 2304 in^2

To transfer 35,445 watts to the load, the heater must operate at 1686°F which is below the heater rating to 1800°F.

Hitco

Application Guide

Electric Heaters

Examples of Applications

Continued

Conclusion

From the example presented here, it appears that the system will function well. It is important to note that all of the permutations have not been. considered in this example. to insure satisfactory performance and life, the aging characteristics of the aging characteristics of the crucible must also be considered. Over a long period of time, reduced thermal conductivity will require that a higher crucible surface temperature is required to get heat transfer to the aluminum. As the crucible temperature must increase, the heater temperature must also increase.

From a practical standpoint, small differences in diameters have little effect on the heater temperatures. Larger differences (especially at small sizes) can have a marked effect.

Emissivities of the various surfaces can also have important effects on the resultant heater temperatures.

It is important to use values that are accurate, or to test prototypes during the design and development stage.

Control Requirements

Design-The aluminum crucible requires a unique control system, a design with cascaded control outputs, which not only controls aluminum temperature via "hold" and "high melt" heaters, but also controls the surface temperature of the heaters them selves. In addition, high and low limit control must provide fail-safe protection for the crucible and the aluminum charge.

Primary Control-A Hitco SERIES 988 microprocessor based control is the recommended primary control is the recommended primary control for the crucible. The SERIES 988 has a dual output, heat PID-heat on-off configuration with a Type N thermocouple sensor in a protective tube in the molten aluminum. The Type N thermocouple is excellent for long sevsor life at high temperatures. The 988 controls half of the 12 heaters with Set Point 1 at 1350°F and the other set of six heaters with on-off Set Point 2 at a differentiall 20°F less. A Hitco DIN-A-MITE switches power to each set of heaters. In addition, to extend the life of the two sets of heaters, a special set point interchange switch enables monthly rotation. The hold heaters become the boost heaters and vice versa.

Heater Surface Control-To further protect the ceramic fiber heaters a second thermocouple fiber heaters a second thermocouple is used to monitor the face temperature of the heaters. This sensor is connected to input 2 fo the 988 which is set up for cascade control. The rH2 value, range high Z is set to limit the heater to a maximum temperatures of 1800°F. The Type N thermocouple sensor is placed directly against the heater face.

High and Low Limit Control- Because both over-and undertemperatures are potentially damaging to the crucible system and the aluminum charge, a Hitco limit controller with a mercury displacement realy is used to ensure fail-safe protection for the system. The limit controller takes a Type K thermocouple input. It will sever power to the heaters at 1825°F heater surface temperature, and turn on a red strobe alarm. Low alarm input comes directly from the input terminals of the SERIES 988. At 1200°F, the low limit SP of the 988 will also activate the red strobe indicator. A feature of the SERIES 988 allows a low alarm condition to be ignored on start-up.

Hitco

Application Guide

Electric Heaters

Examples of Applications

Continued

Objective

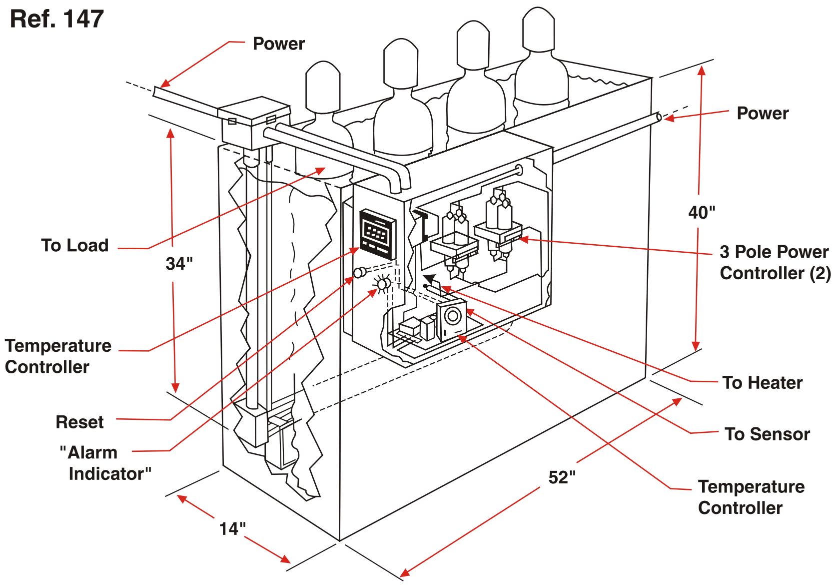
A manufacturing process requires nitrogen gas which is supplied from standard steel gas cylinders. The system operates at low pressure, below 120 psi, and the cylinders must be heated to 140°F. A steel tank 52 inches long X 14 inches wide X 40 inches high holds four cylinders plus 48 gallons of heated water. The tank weighs 100 lbs and is covered with two inch thick insulation. One hour is allowed for preheating the tank, water bath and two gas cylinders. Two additional nitrogen cylinders are then put into he bath and allowed to warm-up for 15 minutes as the first pair is used. They are then used during the following 15 minutes while the next pair is warming up and s on. Each cylinder weighs 55 lbs empty and 65 lbs when full. Ambient temperature is 70°F. Power available is 240 volts, 3-phase.

Power Requirements

The following steps illustrate the calculations to estimate the power required to preheat the system, to heat the gas cylinders and to replace heat losses.

Heating Liquid in a Tank

Ref. 147



Step 1: Initial Heating of Tank, Water and gas Cylinders

From Equation 1, (Page 16)

a. Tank

$$QA = \frac{w \cdot Cp \cdot \Delta T}{3.412}$$

$$= \frac{(100\text{ lbs}) \cdot (0.12\text{ Btu/lb} \cdot °F) \cdot (70°F)}{3.412\text{ Btu/Wh}}$$

= 246 Wh

where:

W = weight of tank = 100 lbs

Cp = specific heat of steel = 0.12 Btu/lb • °F

ΔT = temperature rise = 140°F-70°F = 70°F

b. Water

$$Q_A = \frac{(400\text{lbs}) \cdot (1.0\text{ Btu/lb} \cdot °F) \cdot (70°F)}{3.412\text{ Btu/Wh}}$$

= 8206 Wh

where :

w = weight of water = volume • density

$$= 48\text{ gal} \cdot \frac{1\text{ ft}^3}{7.48\text{ gal}} \cdot 62.3\text{ lbs/ft}^3 = 400\text{ lbs}$$

C_p = specific heat of water = 1.0 Btu/lb • °F

ΔT = 70°F

Examples of Applications

Continued

c. Gas cylinders

The energy requirements of both the steel cylinder and nitrogen gas must be calculated.

Steel cylinder :

$$Q = \frac{(55\ \text{lbs}) \cdot (0.12\ \text{Btu/lb} \cdot {}^\circ\text{F}) \cdot (70^\circ\text{F})}{3.412\ \text{Btu/Wh}}$$

$$= 135\ \text{Wh}$$

where :

w = weight of each cylinder = 55 lbs

Cp = specific heat of steel = 0.12 Btu/lb . °F

ΔT = 70°F

Nitrogen gas:

$$Q_A = \frac{(10\ \text{lbs}) \cdot (0.249\ \text{Btu/lb} \cdot {}^\circ\text{F}) \cdot (70^\circ\text{F})}{3.412\ \text{Btu/Wh}}$$

$$= 51\ \text{Wh}$$

where :

w = weight of nitrogen = 10 lbs

CP = specific heat of nitrogen = 0.249 Btu/lb-°F

Δ = 70°F

Total for two gas cylinders:

$Q_A = 2 . (135 + 51) = 372$ Wh

d. Total

$Q_A = 246 + 8206 + 372$

$= 8824$ Wh

Step 2: Heating of Gas Cylinders During the Operating Cycle

Since two gas cylinders are used for each cycle, refer back to Step 1, part c,

$Q_B = 2 \cdot (135 + 51)$

$= 372$ Wh

Step 3: Heat Required to Melt or Vaporize Materials During Start-Up

Not required as no materials change phase.

$Q_C = 0$

Step 4: Heat Required to Melt or Vaporize Materials During Operating Cycle

Not required as no materials change phase.

$Q_D = 0$

Examples of Applications
Continued

Step 5: Determine Thermal System Heat Losses

a. Convection and radiation losses from insulated tank

from Equation 3 D, (Page 18)

Q_{L4} = $A \cdot F_{SL} \cdot t_e$
= $(5280\ in^2) \cdot (0.03\ W/in^2) \cdot (1\ hr.)$
= 158 Wh

Where :

A = exposed surface area
= $(2 \cdot 14 in. \cdot 40\ in.) + (2.52\ in. \cdot 40\ in.) = 5280\ in^2$
F_{SL} = surface loss factor for 2 inch insulation at $\Delta T = 70°F$
= 0.03 W/in^2
t_e = exposure time = 1 hour

b. Convection and radiation losses from water surface

From Equation 3D, (Page 18).

Q_{L4} = $(728\ in^2) \cdot (1.7\ W/in^2) \cdot (1 hr)$
= 1238 Wh

where :

A = water surface area = $14\ in. \cdot 52\ in. = 728\ in^2$
F_{SL} = surface loss factor for water at 140°F
= $1.7\ Win^2$

c. Total Losses

$Q_L = 158 + 1238 = 1396$ Wh

Step 6: Calculate Start-Up Power Requirements

From Equation 4, (Page 18) using a 10 percent safety factor,

$$\text{Start-Up Power} = \left[\frac{Q_A + Q_C}{t_s} + \frac{2}{3}\left(\frac{Q_L}{t_e}\right)\right] \cdot (1 + S.F.)$$

$$= \left[\left(\frac{8824 + 0\ Wh}{1\ hr}\right) + \frac{2}{3}\left(\frac{1396\ Wh}{1 hr}\right)\right] \cdot (1.1)$$

$$= 10{,}730\ W$$

were :

Q_A = 8824 Wh
Q_C = 0
Q_L = 1396 Wh
t_s = start-up time = 1 hour
t_e = exposure time for losses = 1 hour
S.F. = safety factor = 10 percent

Hitco

Application Guide

Electric Heaters

Examples of Applications

Continued

Step 7: Calculate Operating Power Requirements

From Equation 5, (Page 18) using a 10 percent safety factor,

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

$$= \left[\frac{372\ Wh}{0.25\ hr} + \frac{1396\ Wh}{1\ hr}\right] \cdot (1.1)$$

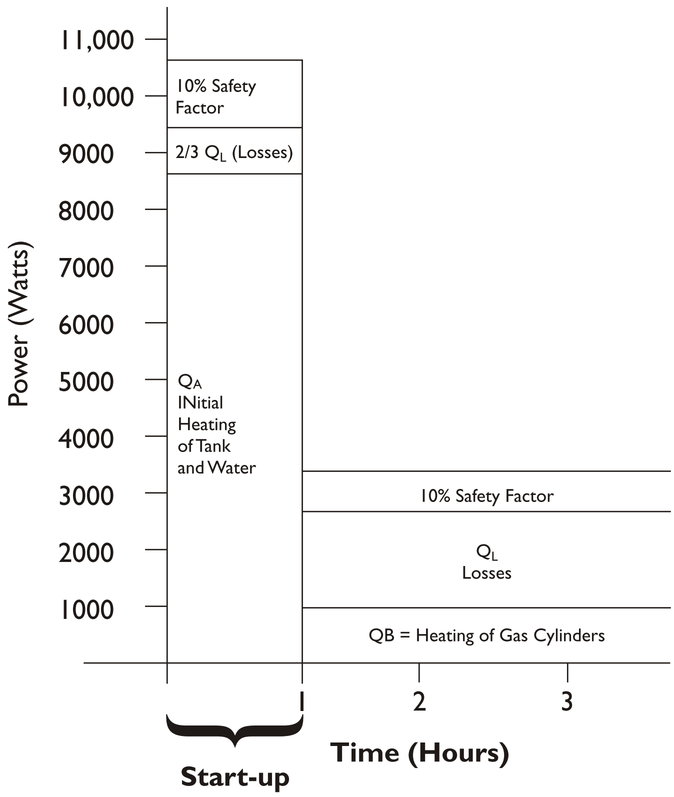
$$= 3172\ W$$

Where :

Q_B = 372 Wh
Q_D = 0
Q_L = 1396 Wh
t_c = cycle time = 15 min. = 0.25 hr
t_e = 1 hr
S.F. = safety factor = 10 percent

Heating Liquid in a Tank Power Evaluation

Ref. 148



Heater Recommendation

The heating requirement is determined by eigher the start-up or the operating power, whichever is greater. In this case 10.7 kilowatts are required for start-up.

A stock 12 kilowatts over-the-side immersion heater is recommended; an "L" elements rated at 48 W/in 2. The element length is about 38 inches and is spaced four inches above the bottom of the tank. The elements should be protected against damage by the gas cylinders.

Control

The control requirements here do not demand a high degree of controllability. The 48 gallons of water represent a large thermal mass; overshoot is not anticipated. nor is it a problem. The Hitco SERIES SD digital indicating control with PID and auto-tuning is the recommended controller. In addition, a Hitco limit controller will protect the heater when the tank is empty. A Hitco DIN-A-MITE power controller will provide power-switching for the SERIES SD.

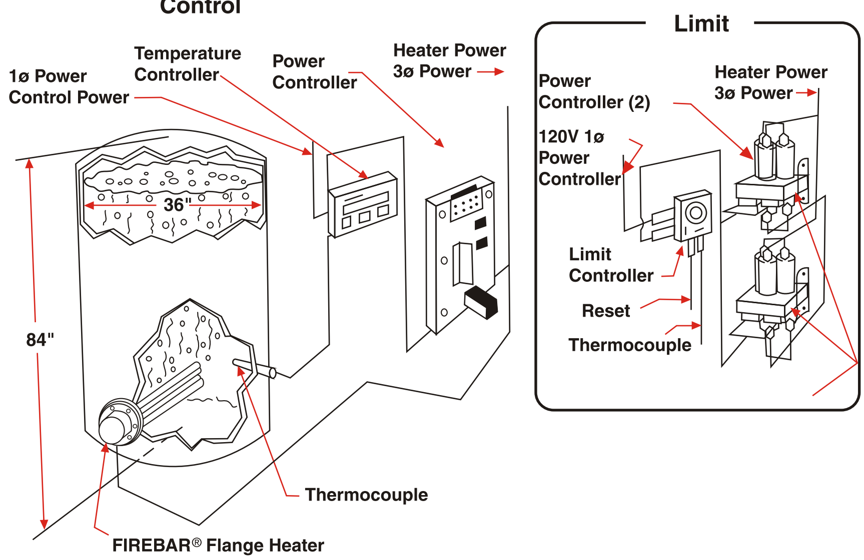
Hitco

Application Guide
Electric Heaters

Examples of Applications
Continued

Objective
A waste water treatment plant requires heating four gallons per minute of treatment water from 70-150°F. The water contains traces of electrolytic cleaners, so it is contained in a 36 inch diameter by 84 inch tall, 350 gallon polypropylene receiver tank. A four inch - 150 lb mating flange is available at the bottom of the tank. The customer has expressed concern about the possibility of corrosion and requests a lower watt density heater rated at 50 kW.

Heating a Flowing Liquid
Ref. 149



Step 1: Initial Heating of the Water and Tank
Because the process is a continuous operation, there will not normally be any start-up period, When the process is interrupted for periodic maintenance though. a maximum of 12 hours for heat-up is requested. With this long of a start-up period, it is likely that the normal operating power will meet this requirement, but it is always advisable to check. From Equation 1, (Page 16)

a. Tank
The tank is made of polypropylene and we will assume it is an insulator, so heat-up of tank will be negligible.

b. Water

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

$$= \frac{(2915 \text{ lbs}) \cdot (1.0 \text{ Btu/lb} \cdot {}^\circ F)\ (80^\circ F)}{3.412 \text{ Btu/Wh}}$$

Q_A = 68,350 Wh

where :
W = weight of water = volume • density

$$= (350 \text{ gal}) \cdot \left(\frac{1 \text{ ft}^3}{7.48 \text{ gal}}\right) \cdot \left(\frac{62.3 \text{ lbs}}{1 \text{ ft}^3}\right)$$

= 2915 lbs

C_p = specific heat of water = 1.0 Btu.lb.°F
ΔT = 150°F - 70°F = 80°F

Application Guide
Electric Heaters

Examples of Applications
Continued

Step 2: Heating of Water During the Operating Cycle
The following is the energy needed to heat the treatment water during actual operation. Even though he customer has specified a given process parameters. From Equation 1, (Page 16).

$$Q_B = \frac{W \cdot C_p \cdot \Delta T}{3.412}$$

$$= \frac{(2000\ lbs) \cdot (1.0\ Btu/lb \cdot {}^\circ F) \cdot (80^\circ F)}{3.412\ Btu/Wh}$$

$$= 46{,}890\ Wh$$

where :
w = weight of water per hour
= volume • density

$$= (4\ gpm) \cdot (60\ min) \cdot \left(\frac{1\ ft^3}{7.48\ gal}\right) \cdot \left(\frac{62.3\ lbs}{1\ ft^3}\right)$$

= 2000 lbs/hr

C_p = specific heat of water = 1.0 Btu/lb • °F
ΔT = 150° - 70°F = 80°F

Step 3: Heat Required to Melt or Vaporize Materials During Initial Heating
Not required since the water does not change phase.
Q_C = 0

Step 4: Geat Required to Melt or Vaporize Materials During Operating Cycle
Not required since the water does not change phase.
Q_D = 0

Step 5 : Determine Thermal System Heat Losses
Because polypropylene is a poor thermal conductor, we will assume it acts as an insulator, and use one inch of insulation as an equivalent value.
From Equation 3D, (Page 18)
$Q_{L4} = A \cdot F_{SL} \cdot t_e$
= (10,520 in²) • (0.05 W/in²) • (12 hrs)
Q_L = 6312 Wh

where :
A = exposed surface area

$$= (36\ in. \cdot \pi \cdot 84\ in.) + \left[\frac{\pi \cdot (36\ in.)^2}{4}\right]$$

= 10,520 in²

F_{SL} = surface loss factor for 1 inch insulation at ΔT = 80°F
= 0.05 W/in²
t_e = exposure time = 12 hrs

Application Guide
Electric Heaters

Examples of Applications
Continued

Step 6: Calculate Start-up Power Requirements
From Equation 4 (Page 18), using a 10 percent safety factor,

$$\text{Start-up Power} = \left[\frac{Q_A + Q_C}{t_s} + \frac{2}{3}\left(\frac{Q_L}{t_e}\right)\right] \cdot (1 + S.F.)$$

$$= \left[\left(\frac{68{,}350\ \text{Wh}}{12\ \text{hrs}}\right) + \frac{2}{3}\left(\frac{6312\ \text{Wh}}{12\ \text{hrs}}\right)\right] \cdot (1.1)$$

$$= 6050\ \text{W}$$

where :

Q_A = 68,350 Wh
Q_C = 0
Q_L = 6312 Wh
t_s = start-up time = 12 hrs
t_e = exposed time = 12 hrs
S.F. = safety factor = 10%

Step 7: Calculate Operating Power Requirements
From Equation 5 (Page 18), using 10 percent safety factor,

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

$$= \frac{46{,}890\ \text{Wh}}{1\ \text{hr}} + \frac{526\ \text{Wh}}{1\ \text{hr}} \cdot (1.1)$$

$$= 52{,}100\ \text{watts} = 52.1\ \text{kW}$$

where

Q_B = 46,890 Wh
Q_D = 0
Q_L = during operation, losses are evaluated on a per hour basis, therefore: (10,520 in2) . (0.05 W/in2) . (1 hr) = 526 Wh
t_c = cycle time required = 1 hr
t_e = exposure time = 1 hr
S.F. = safety factor = 10%

Application Guide

Electric Heaters

Examples of Applications
Continued

Heater Recommendation

The customer's requested value of 50 kilowatts appears to be correct.This specific installation will limit our choices to a four inch-150 lb flange heater with a maximum immersed length of 36 inches A traditional approch would be a four inch flange with six 0.475 inch diameter tubular elements. The watt density would be :

Control

A SERIES SD is used to switch a power controller which in turn switches the heaters. A limit controller is used with a mechanical contactor as over temperture protection.

$$W/in^2 = \frac{5000\,W}{1\,hr} = 93\,W/in^2$$

where:

$$W/in^2 = \frac{W}{\text{active heater surface area}}$$

$$= \frac{\text{heated length}}{\text{element}}\,[in.] \cdot \frac{\text{surface area}}{\text{element}} \cdot \left[\frac{in^2}{in.}\right] \cdot \frac{\text{elements}}{\text{flange}}$$

heated length = (30 inches immersed) • (2 lengths/element)

surface area for

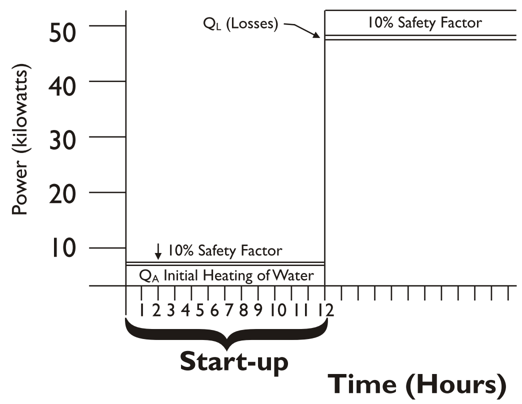
0.475 inch diameter = 1.49 in2/in.

surface area = (30 in.) • (2) • (1.49 in2/in.) • (6 elements)

= 536 in^2

Heating a Flowing Liquid Power Evaluation

Ref. 150



Compare this traditional approach to a FIREBAR® Flange heater, with six FIREBAR elements.

$$W/in^2 = 60.4 = \frac{50{,}000\text{ watts}}{828\,in^2}$$

where :

surface area of FIREBAR = 2.3 in^2/in.

surface area = (30 in.) • (2) • (2.3 in^2/in.) • (6 element)

= 828 in^2

Clearly the FIREBAR® flange provides a better solution with a 35 percent reduction in watt density. Incoloy® elements and a 304 stainless steel flange will be used because of the traces of corrosive cleaners.

Application Guide
Electric Heaters

Examples of Applications
Continued

Objective

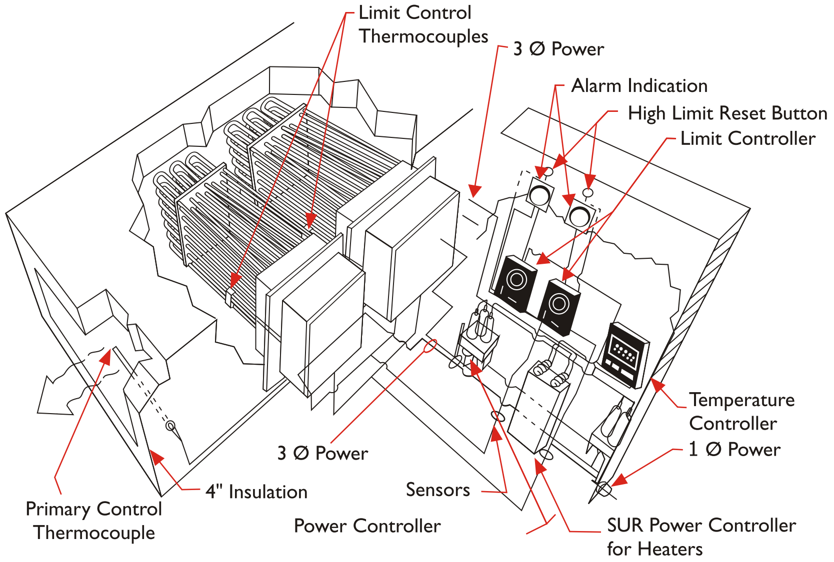
A drying process for unfired ceramics requires 780 cubic feet per minute (CFM) of air at 5600F± 20oF. The air temperature at the blower exit is 90oF and the air is delivered to the dryer through a duct 19 feet in length. The duct is 22 inches wide X 15 inches high and is wrapped with four inch thick insulation.

The equipment layout dictates that the duct heaters may be located no closer than 12 feet to the dryer. The plant ambient temperature is 70oF. Power available is 240/480 volt three phase or single phase.

Power Requirements

The following steps illustrate the calculations to estimate the heat needed for the process air and to compensate for duct losses. There is no start-up heating required.

Ref. 151



Step 1 : Initial Heating of Materials

Not required, because this application is a continuous air flow process

$Q_A = 0$

Step 2 : Heating of Air During Operation

From Equation 1, (Page 16)

$$Q_B = \frac{W \cdot Cp \cdot \Delta T}{3.412}$$

$$= \frac{(1825 \text{ lbs}) \cdot (0.245 \text{ Btu/lb} \cdot {}^\circ\text{F}) \cdot (470^\circ\text{F})}{3.412 \text{ Btu/Wh}}$$

= 61,591 Wh

where:

density of air at 560°F from Reference 137 (Page 143) = 0.039 lbs/ft³

w = weight of air per hour

$$= \text{volume per min (CFM)} \cdot \frac{60 \text{ min}}{\text{hr}} \cdot \text{density (lbs/ft}^3)$$

$$= 780 \text{ CFM} \cdot \frac{60 \text{ min}}{\text{hr}} \cdot 0.039 \text{ lbs/ft3}$$

= 1825 lbs/hr

C_P = specific heat of air at 90°F = 0.24 Btu/lb · °F, at 560°F = 0.25; average = 0.245 Btu/lb · °F

ΔT = temperature rise = 560°F - 90°F = 470°F

Examples of Applications
Continued

Step 3: Heat Required to Melt or Vaporize Materials During Initial Heating
Not required as the air does not change phase during heating.

$Q_C = 0$

Step 4: Heat Required to Melt or Vaporize Materials During Operating Cycle
Not Required as the air does not change phase during heating.

$Q_D = 0$

Step : Determine Thermal System Heat Losses
Radiation and convection losses

From Equation 3D, (Page 18)

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

$= (74\ ft^2) \cdot (20\ W/ft^2) \cdot (1\ hr)$

$Q_L = 1480\ Wh$

where :

A = exposed surface area

$$= 12\ ft \cdot 2 \cdot \frac{(22\ in. + 15\ in.)}{12\ in./ft} = 74\ ft^2$$

F_{SL} = surface loss factor at $\Delta T = 490°F$ and 4 inch insulation

= $20\ W/ft^2$ from Ref. 12 (Page 28)

t_e = exposure time = 1 hr

Step 6 : Calculate Star-up Power Requirements
Not required, because this application is a continuous air flow process.

$PS = 0$

Step 7: Calculate Operating Power Requirements
From Equation 5, (Page 18) using a 10 percent safety factor,

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

$$= \left[\frac{61{,}591\ Wh}{1\ hr} + \frac{1480\ Wh}{1\ hr}\right] \cdot (1.1)$$

$$= 69{,}378\ \text{watts} = 69.4\ \text{kw}$$

where :

Q_B = 61,591 Wh

Q_D = 0

Q_L = 1480 Wh

t_c = 1 hour

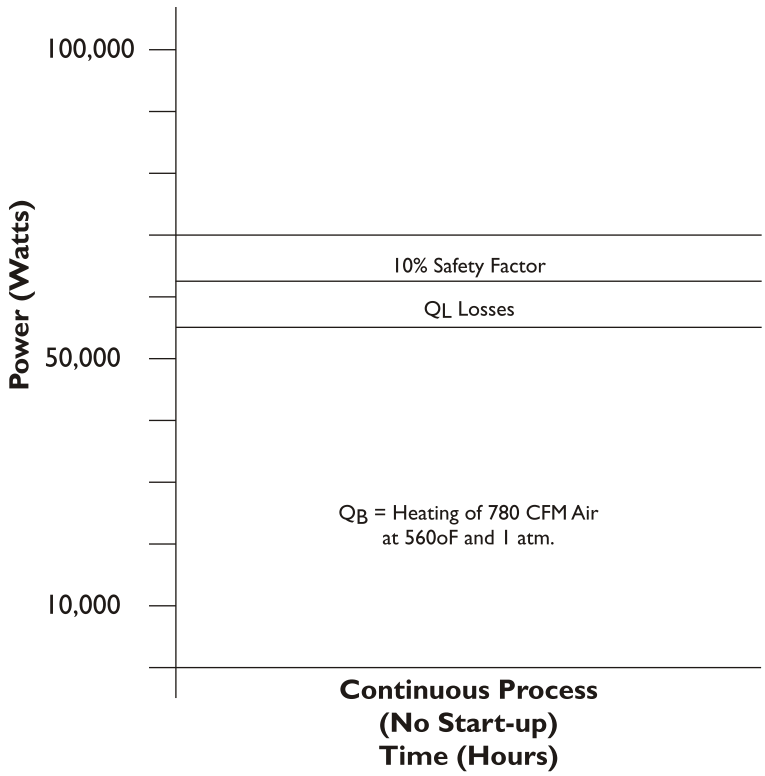
t_e = 1 hour

S.F. = safety factor = 10%

Application Guide
Electric Heaters

Examples of Applications
Continued

Air Duct Heater Power Evaluation
Ref. 152



Heater Recommendations

The duct size of 15 inch X 22 inch is generally too small for a single 75 kilowatts unit. Therefore, two stock 36 kilowatts. 480 volt three phase units will be installed in series. Heating elements are tubular-type 0.430 inch diameter Incoloy® rated rated at 20 W/in2.

Minimum air velocity of 180 ft/min must be maintained to provide sufficient heat transfer to prevent excessive element temperatures. The following are estimates of air velocity at the inlets of the two duct heaters to verify that the air velocity is sufficient.

While the mass flow rate through the duct is constant, the CFM and velocity are not, because they are determined by the iar density which varies with temperature. As previously calculated the weight of air per hour = 1825 lbs/hr.

a. Air velocity v_1 at the inlet to duct heater # 1

$$V1 = \frac{\text{volume per min. (CFM)}}{\text{duct area (ft}^2\text{)}} = \frac{422}{2.29} = 184 \text{ ft/min.}$$

where :

$$CFM_I = \frac{\text{weight of air per hour (lbs)}}{\text{60 min/hr} \cdot \text{density (lbs/ft3)}}$$

$$= \frac{\text{1825 lb/hr}}{\text{60 min/hr . 0.072 lbs/ft3}} = 422 \text{ CFM}$$

density = 0.072 lbs/ft^3 @ 90°F from Reference 137 (Page 143)

$$\text{duct area} = \frac{\text{22 in.} \cdot \text{15in.}}{\text{144 in2/ft}^2} = 2.29 \text{ ft}^2$$

Examples of Applications

Continued

b. Air velocity v2 at the intel to duct heater #2

$$V_2 = \frac{\text{volume per min (CFM)}}{\text{duct area (ft}^2\text{)}} = \frac{596}{2.29} = 260 \text{ ft/min}$$

where :

$$CFM_2 = \frac{\text{weight of air per hr (lbs)}}{60 \text{ min/hr} \cdot \text{density (lbs/ft}^3\text{)}}$$

$$= \frac{1825 \text{ lb/hr}}{60 \text{ min/hr} \cdot 0.051 \text{ lb/ft}^3} = 596 \text{ CFM}$$

The temperature at the inlet to duct heater #2 is the average of the heated and unheated air temperatures by assuming that each 36 kw heater supplies onehalf of the heat:

$$T_2 = \frac{(560 + 90)}{2} = 325°F$$

density = 0.051 lbs/ft^3 @ 325°F from Reference 137 (Page 143)

Control Requirements

Control accuracy in this application is not critical (±20oF), but digital indication is required. In addition, limit controllers with thermocouples must monitor the sheath temperature of each heater. The Hitco SERIES SD with Type J thermocouple input is the correct controller choice. A Hitco limit controller is recommended, providing two channels of high limit control with Type J thermocouple inputs from the heaters. Each heater will be delta connected across the 480 volt, three-phase line and switched by a SCR power switching device for long. dependable service and heater life.

Hitco

Application Guide

Electric Heaters

Examples of Applications

Continued

Objective

A manufacturing process requires that 24 inch X 24 inch X 0.031 inch pieces of 304 stainless steel be heated to 300°F in one minute. The stainless steel has a coating with an emissivity of 0.80. A radiant panel can be located two inches above the metal.

F in one minute. The stainless steel has a coating with an emissivity of 0.80. A radiant panel can be located two inches above the metal.

Drying a Moving Web of Cloth

1. Collect the date. make assumptions. To uniformly heat the product, choose a heater size that overlaps an amount equal to the distance between the heater and the sheet of steel, i.e.:
   Heater Size = 28 in. • 28 in.
   - $\Delta T = 300 - 60 = 240°F$
   - Weight/in^2 = 500 lbs/ft^3 • 1 ft^3/1728 in^2 • 0.031 in. thick = 0.00897 lbs/in2*
   - Specific heat = 0.12 Btu/lb°F*
   - Time = 1 minute = 0.0167 hrs
   - Emissivity of product = Ep = 0.080

2. Determine the wattage required to heat one square inch of the material.

$$\text{Watts} = \frac{w \cdot \text{specific heat} \cdot \Delta T}{\text{Time} \cdot 3.412\ \text{Btu/Wh}}$$

$$\text{Watts} = \frac{0.00897\ \text{lbs/in}^2 \cdot 0.12\ \text{Btu/lb°F} \cdot 240°\text{F}}{0.0167\ \text{hrs.} \cdot 3.412\ \text{Btu/Wh}}$$

$$\text{Watts} = 4.54\ \text{W/in}^2$$

3. Using the radiant heat transfer equation, determine the radiant heater temperature needed to transfer the required wattage found above.

$$\text{W/in}^2 = \frac{S(Th^4 - Tp^4) \cdot E \cdot F}{144\ \text{in}^2/\text{ft}^2 \cdot 3.412\ \text{Btu/Wh}}$$

A. Compute the view factor F

The heater is 28 in. • 28 in., located two inches from the product.

$$M = \frac{28}{2} -14 \qquad N = \frac{28}{2} = 14$$

$$F = 0.85$$

B. Compute the effective emissivity (E).

Emissivity of heater = Eh = 0.85

$$E = 1 \quad \frac{1}{\frac{1}{Eh} + \frac{1}{Ep} - 1} = \frac{1}{\frac{1}{0.85} + \frac{1}{0.8} - 1} = 0.70$$

C. Determine the average product temperature (Tp)

$$Tp = \frac{300 + 60}{2} = 180°F = 640°R$$

Application Guide

Electric Heaters

Examples of Applications

Continued

D. Plug into the radiant heal transfer equation

$$W/in^2 = \frac{S(Th^4 - Tp^4) \cdot E \cdot F}{144\ in^2/ft^2 \cdot 3.412\ Btu/Wh}$$

From above we found:

E = 0.70

F = 0.85

TP = 640°R

Required W/in^2 = 4.54

Therefore:

$$4.54\ W/in^2 = \frac{S(Th^4 - (640)^4) \cdot 0.7 \cdot 085}{144\ in^2/ft^2 \cdot 3.412\ Btu/Wh}$$

$$7.6\ W/in^2 = \frac{S(TH^4 - (640)^4)}{144\ in^2/ft^2 \cdot 3.412\ Btu/Wh}$$

$S = 0.1714 \cdot 10^{-8}$ Btu/hr ft^{2}°R^4

E. Determine the required heater temperaure (Th)

All information required to solve the above equation for the heater temperature (Th) is now available. Note that the equation gives Th in °R.

Th (°F) = Th (°R) - 460

From the graph or the calculation, find:

Th = 780°F

To transfer the required watts, the heater must operate at 780°F.

Comments/Questions

What is the required heater watt density?

If selecting a Hitco RAYMAX® 1120 for this application, this heater requires about 9W/in2 to maintain 780oF face temperature in open air. In this application, slightly less would be required since some of the radiant energy that is reflected off of the 0.80 emissivity surface of the metal is reflected back into the heater and re-absorbed. This would be a much more significant factor if the product surface had a lower emissivity, say 0.5.

What about losses off the surface of the metal as it heats up?

Generally, the air temperature between the heater and the product is higher than the product temperature, so some convection heating takes place. In this application, assume the plate is resting on a good heat insulator and there is very little air movement. If this is not the case, then these losses must be estimated and added to the required wattage determined above.