How Much Heat do You Need? Calculations for Heat Energy

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Most electrical heating problems can be readily solved by determining the heat required to do the job. 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.

Defining the heating problem

Your heating problem must be clearly stated, paying careful attention to defining operating parameters. Before going any further, you should ensure you have the following information:

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

The thermal system you are designing may not take into account all the possible or unforeseen heating requirements, so remember the safety factor. A safety factor increases heater capacity beyond calculated requirements.

Calculating power requirements

The total heat energy (kWH or Btu) required is either the heat required for start-up or the heat required to maintain the desired temperature. This depends on which calculated result is larger.

The power required (kW) is 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 separately. However, a short method can be used for a quick estimate of the heat energy required.

Short method

Start-up Watts = A + C + 2/3L + Safety Factor

Operating Watts = B + D + L + Safety Factor

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

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

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

The equation for A and B (Absorbed Watts for raising temperature)

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

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

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

The equation for C and D (Absorbed watts for melting or vaporizing)

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

L = Watts lost from surfaces by conduction use, radiation use heat loss curves or convection use heat loss curves

The equation for L (Lost conducted Watts)

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

Power Calculations

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

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

Since all calculations are in Watts, an additional conversion of 3.412 Btu = 1 W-hr is introduced.

$$Q_A \text{ or } Q_B = \frac{w \times Cp \times \Delta T}{3.412}$$

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

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

w = Weight of Material (lb)

Cp = Specific Heat of Material (Btu/lb x °F)

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

Heat Required to Melt or Vaporize a Material

The heat needed to melt material is known as the latent heat of fusion and represented by H_f. Another state change is involved in vaporization and condensation. The latent heat of vaporization H_v of the substance is the energy required to change a substance from a liquid to a vapor. This same amount of energy is released as the vapor condenses back to a liquid.

$$Q_C \text{ or } Q_D = \frac{w \times H_{f \text{ or } v}}{3.412}$$

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

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

w = Weight of Material (lb)

H_f = Latent Heat of Fusion (Btu/lb)

H_v = Latent Heat of Vaporization (Btu/lb)

Conduction Heat Losses

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

$Q_{L1} = \quad k \, x \, A \, x \, \Delta T \, x \, te$*[1] (https://watlow365-my.sharepoint.com/personal/cchamberlain_watlow_com/Documents/Watlow.com/Blogs/Watlow_%20How%20much%20heat%20do%20you%20need%20v2%20.docx#*

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3.412 x L

Q_{L1}= Conduction Heat Losses (Wh)

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

A = Heat Transfer Surface Area (ft^2)

L = Thickness of Material (in.)

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

te = Exposure Time (hr)

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 liquidas a result of the movement of the masses of the fluid.

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

Q_{L2}= Convection Heat Losses (Wh)

A= Surface Area (in2)

F_{SL} = Vertical Surface Convection Loss Factor (W/in2) Evaluated at Surface Temperature

C_F= Surface Orientation Factor: Heated surface faces up horizontally (1.29), Vertical (1.00), Heated surface faces down horizontally (0.63)

Radiation Heat Losses

Radiation losses are not dependent on the orientation of the surface. Emissivity is used to adjust for a material's ability to radiate heat energy.

$Q_{L3} = A \, x \, F_{SL} \, x \, e$

Q_{L3} = Radiation Heat Losses (Wh)

A = Surface Area (in2)

F_{SL} = Blackbody Radiation Loss Factor at Surface Temperature (W/in2)

e = Emissivity Correction Factor of Material Surface

Combined Convection and Radiation Heat Losses

If only the convection component is required, then the radiation component must be determined separately and subtracted from the combined curve.

$Q_{L4} = A \, x \, F_{SL}$

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)

Total Heat Losses

The total conduction, convection and radiation heat losses are summed together to allow for all losses in the power equations.

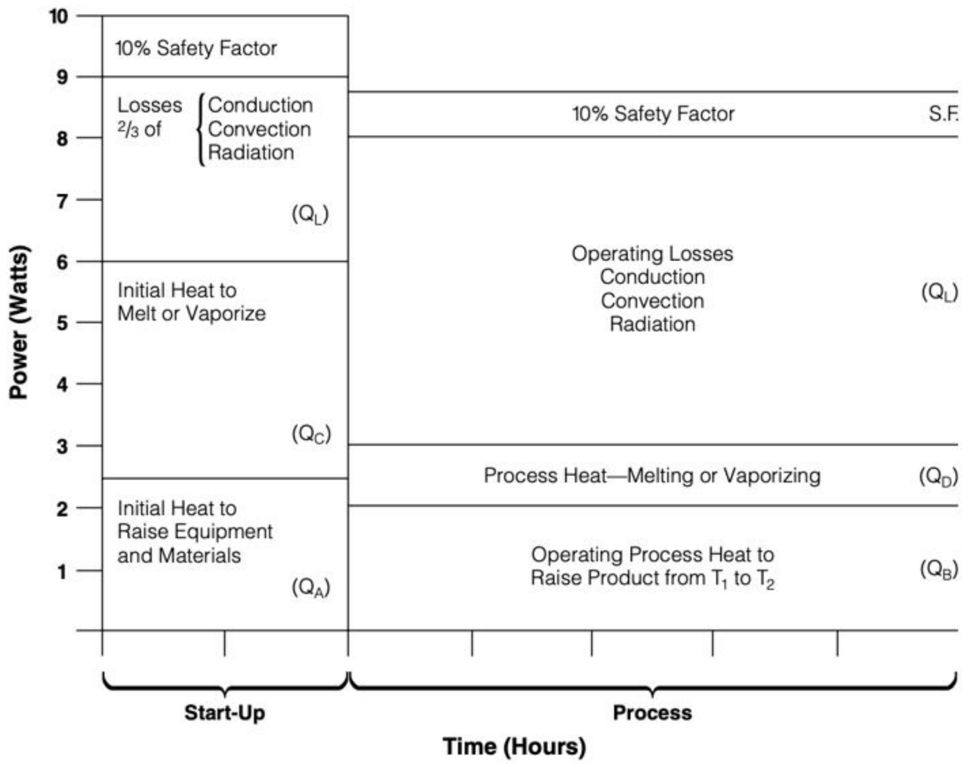
$Q_L = Q_{L1} + Q_{L2} + Q_{L3}$ If convection and radiation losses are calculated separately. (Surfaces are not uniformly insulated and losses must be calculated separately.)

OR

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

Power evaluation

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



(abcimg://startup%20and%20operating%20watts%20chart)

Shown in Reference 1 are the start-up and operating Watts, 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 the effects of lengthening start-up time such that start-up watts equals operating watts (use timer to start system before the shift).

Recognize that more heating capacity exists than is being utilized. (A short start-up time requirement needs more wattage than the process in wattage.)

Identify where most energy is going and redesign or add insulation to reduce wattage requirements.

Having considered the entire system, a review of start-up time, production capacity, and insulating methods should be made. Once you have your required heat, you should consider the application factors of your heater.