Technical Information

Determining Heat Energy Requirements

General Applications

The objective of any heating application is to raise or maintain the temperature of a solid, liquid or gas to or at a level suitable for a particular process or application. Most heating applications can be divided into two basic situations; applications which require the maintenance of a constant temperature and applications or processes which require work product to be heated to various temperatures. The principles and calculation procedures are similar for either situation.

Constant Temperature Applications

Most constant temperature applications are special cases where the temperature of a solid, liquid or gas is maintained at a constant value regardless of ambient temperature. Design factors and calculations are based on steady state conditions at a fixed difference in temperature. Heat loss and energy requirements are estimated using “worst case” conditions. For this reason, determining heat energy requirements for a constant temperature application is relatively simple. Comfort heating (constant air temperature) and freeze protection for piping are typical examples of constant temperature applications. The equations and procedures for calculating heat requirements for several applications are discussed later in this section.

Variable Temperature Applications

Variable temperature (process) applications usually involve a start-up sequence and have numerous operating variables. The total heat energy requirements for process applications are determined as the sum of these calculated variables. As a result, the heat energy calculations are usually more complex than for constant temperature applications. The variables are:

Total Heat Energy Absorbed — The sum of all the heat energy absorbed during start-up or operation including the work product, the latent heat of fusion (or vaporization), make up materials, containers and equipment.

Total Heat Energy Lost — The sum of the heat energy lost by conduction, convection, radiation, ventilation and evaporation during start-up or operation.

Design Safety Factor — A factor to compensate for unknowns in the process or application.

Process Applications

The selection and sizing of the installed equipment in a process application is based on the **larger of two calculated heat energy requirements**. In most process applications, the start-up and operating parameters represent two distinctly different conditions in the same process. The heat energy required for start-up is usually considerably different than the energy required for operating conditions. In order to accurately assess the heat requirements for an application, each condition must be evaluated. The comparative values are defined as follows:

- **Calculated heat energy required for process start-up over a specific time period.**
- **Calculated heat energy required to maintain process temperatures and operating conditions over a specific cycle time.**

Determining Heat Energy Absorbed

The first step in determining total heat energy requirements is to determine the heat energy absorbed. If a change of state occurs as a direct or indirect part of the process, the heat energy required for the change of state must be included in the calculations. This rule applies whether the change occurs during start-up or later when the material is at operating temperature. Factors to be considered in the heat absorption calculations are shown below:

Start-Up Requirements (Initial Heat-Up)

- Heat absorbed during start-up by:
  - Work product and materials
  - Equipment (tanks, racks, etc.)
- Latent heat absorption at or during start-up:
  - Heat of fusion
  - Heat of vaporization
- Time factor

Operating Requirements (Process)

- Heat absorbed during operation by:
  - Work product in process
  - Equipment loading (belts, racks, etc.)
  - Make up materials
- Latent heat absorption during operation:
  - Heat of fusion
  - Heat of vaporization
- Time (or cycle) factor, if applicable

Determining Heat Energy Lost

Objects or materials at temperatures above the surrounding ambient lose heat energy by conduction, convection and radiation. Liquid surfaces exposed to the atmosphere lose heat energy through evaporation. The calculation of total heat energy requirements must take these losses into consideration and provide sufficient energy to offset them. Heat losses are estimated for both start-up and operating conditions and are added into the appropriate calculation.

Heat Losses at Start-Up — Initially, heat losses at start-up are zero since the materials and equipment are all at ambient temperature. Heat losses increase to a maximum at operating temperature. Consequently, start-up heat losses are usually based on an average of the loss at start-up and the loss at operating temperature.

Heat Losses at Operating Temperature — Heat losses are at a maximum at operating temperature. Heat losses at operating temperature are taken at full value and added to the total energy requirements.

Estimating Heat Loss Factors

The heat losses just discussed can be estimated by using factors from the charts and graphs provided in this section. Total losses include radiation, convection and conduction from various surfaces and are expressed in watts per hour per unit of surface area per degree of temperature **(W/hr/ft²/°F)**.

Note — Since the values in the charts are already expressed in watts per hour, they are not influenced by the time factor *“t”* in the heat energy equations.

Design Safety Factors

In many heating applications, the actual operating conditions, heat losses and other factors affecting the process can only be estimated. A safety factor is recommended in most calculations to compensate for unknowns such as ventilation air, thermal insulation, make up materials and voltage fluctuations. As an example, a voltage fluctuation (or drop) of 5% creates a 10% change in the wattage output of a heater.

Safety factors vary from 10 to 25% depending on the level of confidence of the designer in the estimate of the unknowns. The safety factor is applied to the sum of the calculated values for heat energy absorbed and heat energy lost.

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Determining Heat Energy Requirements

Total Heat Energy Requirements

The total heat energy (Q_T) required for a particular application is the sum of a number of variables. The basic total energy equation is:

$$Q_T = Q_M + Q_L + \text{Safety Factor}$$

Where:
Q_T = The total energy required in kilowatts
Q_M = The total energy in kilowatts absorbed by the work product including latent heat, make up materials, containers and equipment
Q_L = The total energy in kilowatts lost from the surfaces by conduction, convection, radiation, ventilation and evaporation
Safety Factor = 10% to 25%

While Q_T is traditionally expressed in Btu's (British Thermal Units), it is more convenient to use watts or kilowatts when applying electric heaters. Equipment selection can then be based directly on rated heater output. Equations and examples in this section are converted to watts.

Basic Heat Energy Equations

The following equations outline the calculations necessary to determine the variables in the above total energy equation. Equations 1 and 2 are used to determine the heat energy absorbed by the work product and the equipment. The specific heat and the latent heat of various materials are listed in this section in tables of properties of non-metallic solids, metals, liquids, air and gases. Equations 3 and 4 are used to determine heat energy losses. Heat energy losses from surfaces can be estimated using values from the curves in charts G-114S, G-125S, G-126S or G-128S. Conduction losses are calculated using the thermal conductivity or *"k"* factor listed in the tables for properties of materials.

Equation 1 — Heat Energy Required to Raise the Temperature of the Materials (No Change of State). The heat energy absorbed is determined from the weight of the materials, the specific heat and the change in temperature. Some materials, such as lead, have different specific heats in the different states. When a change of state occurs, two calculations are required for these materials, one for the solid material and one for the liquid after the solid has melted.

$$Q_A = \frac{\text{Lbs} \times C_p \times \Delta T}{3412 \text{ Btu/kW}}$$

Where:
Q_A = kWh required to raise the temperature
Lbs = Weight of the material in pounds
C_p = Specific heat of the material (Btu/lb/°F)
ΔT = Change in temperature in °F [$T_{2\,(\text{Final})} - T_{1\,(\text{Start})}$]

Equation 2 — Heat Energy Required to Change the State of the Materials. The heat energy absorbed is determined from the weight of the materials and the latent heat of fusion or vaporization.

$$Q_F \text{ or } Q_V = \frac{\text{Lbs} \times H_{fus} \text{ or } H_{vap}}{3412 \text{ Btu/kW}}$$

Where:
Q_F = kWh required to change the material from a solid to a liquid
Q_v = kWh required to change the material from a liquid to a vapor or gas
Lbs = Weight of the material in pounds
Q_{fus} = Heat of fusion (Btu/lb/°F)
Q_{vap} = Heat of vaporization (Btu/lb/°F)

Equation 3 — Heat Energy Lost from Surfaces. The heat energy lost from surfaces by radiation, convection and evaporation is determined from the surface area and the loss rate in watts per square foot per hour.

$$Q_{LS} = \frac{A \times L_S}{1000 \text{ W/kW}}$$

Where:
Q_{LS} = kWh lost from surfaces by radiation, convection and evaporation
A = Area of the surfaces in square feet
L_S = Loss rate in watts per square foot at final temperature ($W/ft^2/hr$ from charts)[1]

Equation 4 — Heat Energy Lost by Conduction through Materials or Insulation. The heat energy lost by conduction is determined by the surface area, the thermal conductivity of the material, the thickness and the temperature difference across the material.

$$Q_{LC} = \frac{A \times k \times \Delta T}{d \times 3412 \text{ Btu/kW}}$$

Where:
Q_{LC} = kWh lost by conduction
A = Area of the surfaces in square feet
k = Thermal conductivity of the material in Btu/inch/square foot/hour (Btu/in/ft^2/hr)
ΔT = Temperature difference in °F across the material [$T_2 - T_1$]
d = Thickness of the material in inches

Summarizing Energy Requirements

Equations 5a and 5b are used to summarize the results of all the other equations described on this page. These two equations determine the total energy requirements for the two process conditions, start-up and operating.

Equation 5a — Heat Energy Required for Start-Up.

$$Q_T = \left(\frac{Q_A + Q_F\,[\text{or } Q_V]}{t} + \frac{Q_{LS} + Q_{LC}}{2}\right)(1 + SF)$$

Where:
Q_T = The total energy required in kilowatts
Q_A = kWh required to raise the temperature
Q_F = kWh required to change the material from a solid to a liquid
Q_V = kWh required to change the material from a liquid to a vapor or gas
Q_{LS} = kWh lost from surfaces by radiation, convection and evaporation
Q_{LC} = kWh lost by conduction
SF = Safety Factor (as a percentage)
t = Start-up time in hours[2]

Equation 5b — Heat Energy Required to Maintain Operation or Process[3].

$$Q_T = (Q_A + Q_F\,[\text{or } Q_V] + Q_{LS} + Q_{LC})(1 + SF)$$

Where:
Q_T = The total energy required in kilowatts
Q_A = kWh required to raise the temperature of added material
Q_F = kWh required to change added material from a solid to a liquid
Q_V = kWh required to change added material from a liquid to a vapor or gas
Q_{LS} = kWh lost from surfaces by radiation, convection and evaporation
Q_{LC} = kWh lost by conduction
SF = Safety Factor (as a percentage)

Equipment Sizing & Selection

The size and rating of the installed heating equipment is based on the larger of calculated results of Equation 5a or 5b.

Notes —

1. **Loss Factors** from charts in this section include losses from radiation, convection and evaporation unless otherwise indicated.
2. **Time (t)** is factored into the start-up equation since the start up of a process may vary from a period of minutes or hours to days.
3. **Operating Requirements** are normally based on a standard time period of one hour ($t = 1$). If cycle times and heat energy requirements do not coincide with hourly intervals, they should be recalculated to a hourly time base.