Technical Information

Heat Transfer Fundamentals & Thermodynamic Properties

Heat Transfer Fundamentals

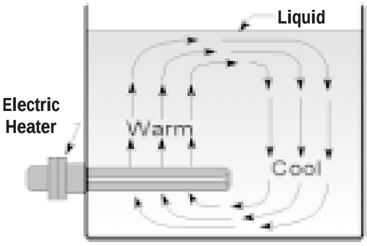
The principles of heat transfer are well understood and are briefly described below. Heat energy is transferred by three basic modes. All heating applications involve each mode to a greater or lesser degree.

- Conduction
- Convection
- Radiation

Conduction is the transfer of heat energy through a solid material. Metals such as copper and aluminum are good conductors of heat energy. Glass, ceramics and plastics are relatively poor conductors of heat energy and are frequently used as thermal insulators. All gases are poor conductors of heat energy. A combination of expanded glass or ceramic fiber filled with air is excellent thermal insulation. Typical conduction heating applications include platen heating (cartridge heaters), tank heating (strip and ring heaters), pipe tracing and other applications where the heater is in direct contact with the material being heated.

Convection is the transfer of heat energy by circulation and diffusion of the heated media. It is the most common method of heating fluids or gases and also the most frequent application of electric tubular elements and assemblies. Fluid or gas in direct contact with a heat source is heated by conduction causing it to expand. The expanded material is less dense or lighter than its surroundings and tends to rise. As it rises, gravity replaces it with colder, denser material which is then heated, repeating the cycle. This circulation pattern distributes the heat energy throughout the media. Forced convection uses the same principle except that pumps or fans move the liquid or gas instead of gravity.

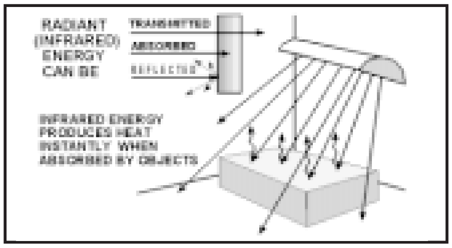
Convection in a Liquid



Typical convection heating applications include water and oil immersion heating, air heating, gas heating and comfort air heating.

Radiation is the transfer of heat energy by electromagnetic (infrared) waves and is very different from conduction and convection. Conduction and convection take place when the material being heated is in direct contact with the heat source. In infrared heating, there is no direct contact with the heat source. Infrared energy travels in straight lines through space or vacuum (similar to light) and does not produce heat energy until absorbed. The converted heat energy is then transferred in the material by conduction or convection.

Radiant Energy (Infrared) Heating



All objects above "absolute zero" temperature radiate infrared energy with warmer objects radiating more energy than cooler objects. Infrared energy radiating from a hot object (heating element) strikes the surface of a cooler object (work piece), is absorbed and converted to heat energy. Paint drying by radiant heaters is a typical application of infrared heating. The most important principle in infrared heating is that infrared energy radiates from the source in straight lines and **does not become heat energy until absorbed by the work product.**

Thermodynamic Properties

All materials have basic physical constants and thermodynamic properties. These constants are used in the evaluation of the materials and in heat energy calculations. The constants and properties most often used are:

- Specific Heat (C_p)
- Heat of Fusion (H_{fus})
- Heat of Vaporization (H_{vap})
- Thermal Conductivity (k)
- Thermal Resistivity (R)

Specific Heat (Quantity of Heat Energy) — All materials contain or absorb heat energy in differing amounts. The quantity of heat energy or thermal capacity of a particular material is called its **specific heat**.

The specific heat of a substance is defined as the amount of heat energy required to raise one pound of the material by one degree Fahrenheit. Specific heat factors are usually defined as British thermal units per pound per degree Fahrenheit **(Btu/lb/°F)**. The specific heat of most materials is constant at only one temperature and usually varies to some degree with temperature. Water has a specific heat of 1.0 and absorbs large quantities of heat energy. Air, with a specific heat of 0.24, absorbs considerably less heat energy per pound.

Heat of Fusion or Vaporization — Many materials can change from a solid to a liquid to a gas. For the change of state to occur, heat energy must be added or released. Water is a prime example in that it changes from a solid (ice) to a liquid (water) to a gas (steam or vapor). If the change is from a solid to a liquid to a gas, heat energy is added. If the change is from a gas to a liquid to a solid, heat energy is released. These energy requirements are called the **heat of fusion** and the **heat of vaporization**. They are expressed as Btu per pound **(Btu/lb)**.

- **Heat of Fusion** is the amount of energy required to transform a material from a solid to a liquid (or the reverse) at the same temperature. Water has a heat of fusion of 143 Btu/lb.
- **Heat of Vaporization** is the amount of energy required to transform a material from a liquid to a gas (or the reverse) at the same temperature. Water has a high heat of vaporization, 965 Btu/lb. Water can transfer large amounts of heat energy in the form of condensing steam.

Thermal Conductivity is the ability of a material to transmit heat energy by conduction. Thermal conductivity is identified as *"k"* and is usually expressed in British thermal units per linear inch (or foot) per hour per square foot of area per degree Fahrenheit. **(Btu/in/hr/ft²/°F) or (Btu/ft/hr/ft²/°F)**. *"k"* factors are used extensively in comfort heating applications to rate the effectiveness of building construction and other materials as thermal insulation. *"k"* factors are also used in the calculation of heat losses through pipe and tank insulation.

Thermal Resistivity or "R" is the inverse of thermal conductivity. Insulating materials are rated by "R" factors. The higher the "R" factor, the more effective the insulation.