1 Introduction

1.1 Relevance of Heat Transfer

Heat transfer is the term used to describe the movement of thermal energy (heat) from one place to another. Heat transfer drives the world that we live in. Look around. Heat transfer is at work no matter where you currently are.

Do you see any buildings? Most modern building are heated and cooled by equipment such as furnaces and air conditioning units that rely on heat exchangers for their operation. In addition, there are many devices within the building that rely on heat transfer to operate. Examples include your computer, light bulbs, toasters, ovens, water heaters, and refrigerators; all of these devices must transfer thermal energy to operate. Many engineers will eventually find jobs in the Heating Ventilation Air-Conditioning and Refrigeration (HVAC&R) industry, which employs engineers to design and maintain building conditioning and related energy systems.

Do you see any vehicles? Most vehicles today employ internal combustion engines in which the chemical energy in fuel is converted into mechanical power to drive the vehicle. A large fraction of the energy in the fuel is converted to thermal energy which must be transferred to the environment in order to keep the engine and related parts from overheating. The “radiator” is a heat exchanger in the vehicle that transfers thermal energy from the engine coolant to the surroundings. Heat transfer governs the design of much of the equipment in a vehicle.

Are you using any electrical power right now? Much of electrical power used in the world is produced by burning a fuel such as coal or natural gas and transferring the thermal energy to water to make steam. The steam drives turbines, which in turn drive generators that produce the electrical power. Thermodynamics dictates the maximum efficiency at which the electrical generation process can occur, but heat transfer governs the actual design of the boiler in which the steam is produced and the condensers in which thermal energy from the cycle is transferred to the environment.

Perhaps you are outdoors, far away from any man-made technology. Even here, heat transfer (and the related science of mass transfer) is important. Heat transfer dictates what clothes you are wearing to maintain comfort. The concept of “wind-chill” is a means of expressing the heat transfer enhancement that results from air movement. On a grander scale, heat transfer regulates the temperature of our environment, balancing solar energy gains with thermal energy radiation from the planet to outer space. A detailed examination of the surroundings, e.g., green leaves on trees, animal fur, etc., shows the different adaptations that living things have made to control their heat transfer rates.

You are likely familiar with the terms global warming and climate change, which are used to describe the increase in the temperature of the environment as a result of human activities. The entire concept of global warming is rooted in heat transfer. A major contributor to global warming is the reduction in thermal energy transport from Earth’s surface to outer space by radiation as a consequence of increased levels of carbon dioxide in the atmosphere that has resulted from the combustion of fossil fuels.

It has always been important for engineers to design efficient products. A more efficient system can be smaller and less expensive to manufacture as well as requiring less energy to operate, thereby reducing operating costs. We find ourselves entering a period of human history where efficient design is more important than it ever has been. Aside from limiting costs, we must also reduce the amount of fuels we consume to preserve our supply of nonrenewable fuels and to limit the climate change that they cause. We must develop alternative systems that rely on renewable energy sources such as solar energy and wind. The efficiency of both renewable and nonrenewable energy systems is primarily driven by the performance of the components within them that are used to transfer heat. The backbone of these systems will be highly effective heat exchangers and they will be designed by engineers who have a thorough understanding of heat transfer. Engineering students with a strong background in thermodynamics, fluids, and heat transfer are increasingly in demand as many of the problems that face the nation and the world center around the effective transfer of heat.

1.2 Relationship to Thermodynamics

The concept of heat is introduced in the study of **thermodynamics**. In thermodynamics, **heat** is defined as the energy that transfers across the boundary of a system as the result of a temperature gradient. Students of thermodynamics typically define **systems** and use these systems to carry out **energy balances**; heat plays a major role in these balances. However, thermodynamics is unconcerned with time and therefore the rates of energy transfer.

Energy balances form the backbone of the study of heat transfer as well. The difference between thermodynamics and heat transfer is that heat transfer problems couple these energy balances with **rate equations** in order to predict and understand the *rate* of heat transfer rather than just the amount.

Thermodynamics teaches us that energy is a conserved quantity (in the absence of nuclear reactions); that is, energy is neither generated nor destroyed. Therefore, an energy balance on a system enforces the idea that the energy entering the system must be equal to the sum of the energy leaving the system and the energy stored within the system:

$$IN = OUT + STORED. \tag{1.1}$$

For energy balances that are written for some finite time period, *IN* and *OUT* represent the amount of energy entering and leaving the system, respectively, and *STORED* represents the amount of energy stored in the system during that time (i.e., the change in the amount of energy that is contained within the system). In a heat transfer problem, these terms will typically represent rates of energy transfer and the rate of energy storage.

Energy can cross a system boundary in the form of heat, work, or with mass (for an open system). Figure 1.1 illustrates an energy balance on an open system (neglecting kinetic and potential energy terms) and results in the equation below:

$$\dot{m}_{in}\, i_{in} + \dot{q}_{in} + \dot{w}_{in} = \dot{m}_{out}\, i_{out} + \dot{q}_{out} + \dot{w}_{out} + \frac{dU}{dt}, \tag{1.2}$$

where the subscript *in* indicates quantities entering the control volume and *out* quantities leaving the control volume. The variable $\dot{m}$ is the mass flow rate crossing the system boundary and i is the specific enthalpy associated with that mass (note that the symbol h is *not* used for specific enthalpy here as it is used extensively in heat transfer literature to represent the heat transfer coefficient). The quantities $\dot{q}$ and $\dot{w}$ are the rates of heat transfer and work transfer, respectively, passing the control surface. Finally, the quantity U is the total amount of internal energy contained within the control volume and $\frac{dU}{dt}$ is its time derivative.

Thermodynamics by itself does not provide any way to compute the rate of heat transfer based on the physical situation (i.e., the geometry, materials, and other conditions associated with the situation). Thermodynamic problems must therefore either provide the heat transfer rate as an input or calculate the heat transfer rate by solving an energy balance like Eq. (1.2) in which $\dot{q}$ is the only unknown. Many problems in thermodynamics assume that a system is **adiabatic** (i.e., $\dot{q} = 0$). *The goal of heat transfer is to provide the tools needed to compute* $\dot{q}$ *based on the details of the situation.*

Thermodynamics problems apply energy balances almost exclusively to finite sized systems or control volumes. For example, in thermodynamics a system might include an entire tank or compressor or heat

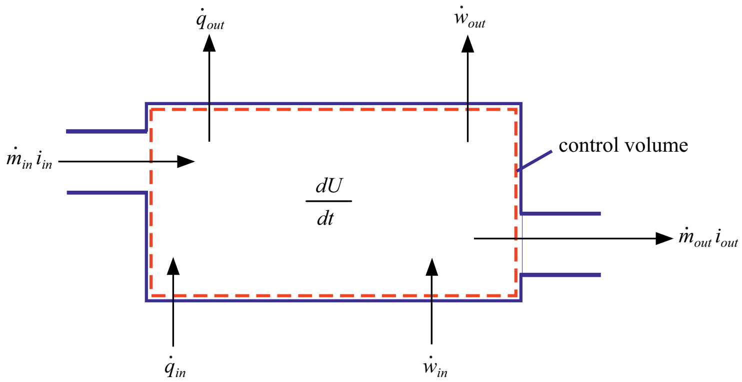

Figure 1.1 General energy balance on an open system.

exchanger. Heat transfer also utilizes energy balances, just like the one shown in Eq. (1.2), but in heat transfer the energy balances are often applied to a *differentially small* control volume. This is done in order to express the result of the energy balance as an ordinary or partial differential equation. Most thermodynamics problems do not require the solution of differential equations; however, many of the problems we encounter in heat transfer will involve differential equations.

Example 1.1

A small freezer uses a thermoelectric cooler to keep biological specimens frozen during shipping. The internal freezer space must be maintained at T_C = –15°C and the ambient temperature is T_H = 30°C. The thermal resistance associated with the freezer walls is R = 5.3 K/W. This thermal resistance is used in the rate equation that computes the heat transfer rate from the ambient air to the contents of the freezer:

$$\dot{q}_{wall} = \frac{(T_H - T_C)}{R}. \tag{1}$$

Obviously, a well-designed freezer will have a large thermal resistance to reduce the need for the thermoelectric cooler to operate. The contents of this book will allow you to estimate the thermal resistance of a freezer given the details of its construction.

The thermoelectric cooler is powered by batteries and has a coefficient of performance, COP = 0.5; recall from thermodynamics that COP is defined as the ratio of the rate of cooling provided by the refrigerator ($\dot{q}_C$) to the power consumed by the cooler ($\dot{w}$). The freezer must operate for $time$ = 2 days. Your research has indicated that the energy density of the lithium-ion batteries used to power the cooler is approximately ed = 120 W-hr/kg.

Determine:

- The electrical power consumed by the thermoelectric cooler and rate of heat transfer from the cooler to the ambient air.
- The mass of batteries required by the system.

Known Values

The known parameters are indicated on the sketch of the freezer shown in Figure 1; when necessary these parameters are converted to base SI units.

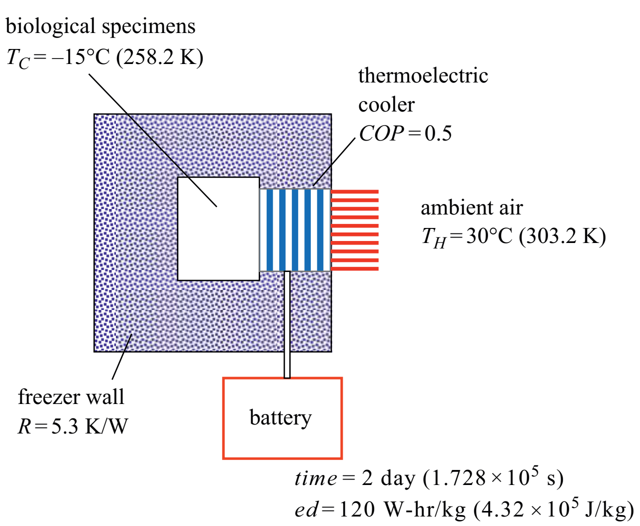

Figure 1 Freezer for biological specimens.

Continued

Example 1.1 (cont.)

Assumption

- Steady-state conditions exist.

Analysis

Equation (1) can be used to determine the rate of heat transfer from ambient to the contents of the freezer, $\dot{q}_{wall}$. An energy balance on the freezer compartment is shown in Figure 2 (left).

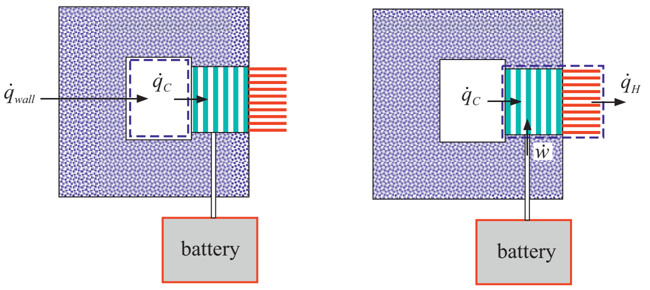

Figure 2 (Left) Energy balance on the freezer compartment and (right) energy balance on the thermoelectric cooler.

Equation (1.2) can be applied to this situation by setting the power and mass flow rate terms to zero. The freezer is assumed to be at steady state so that the energy storage term is also set to zero:

$$\dot{q}_{wall} = \dot{q}_C. \tag{2}$$

The definition of *COP* can be used to determine the power consumed by the cooler:

$$\dot{w} = \frac{\dot{q}_C}{COP}. \tag{3}$$

Figure 2 (right) illustrates an energy balance on the cooler itself (again, assuming steady state):

$$\dot{q}_C + \dot{w} = \dot{q}_H. \tag{4}$$

The amount of energy consumed by the cooler from the battery during the shipping process is obtained by multiplying the steady-state power by the time:

$$W = \dot{w}\ time. \tag{5}$$

The mass of batteries required is obtained using the energy density:

$$m = \frac{W}{ed}. \tag{6}$$

Solution

Equations (1) through (6) can be solved sequentially and explicitly. Here we will solve them by hand:

$$\dot{q}_{wall} = \frac{(T_H - T_C)}{R} = \frac{(303.2 - 258.2)\mathrm{K}}{} \left| \frac{\mathrm{W}}{5.3\ \mathrm{K}} \right. = 8.49\ \mathrm{W}$$

$$\dot{q}_C = \dot{q}_{wall} = 8.49\ \mathrm{W}$$

$$\dot{w} = \frac{\dot{q}_C}{COP} = \frac{8.49\ \mathrm{W}}{} \left| \frac{}{0.5} \right. = \boxed{17.0\ \mathrm{W}}$$

$$\dot{q}_H = \dot{q}_C + \dot{w} = 8.49\ \mathrm{W} + 17.0\ \mathrm{W} = \boxed{25.5\ \mathrm{W}}$$

Example 1.1 (cont.)

$$W = \dot{w}\,time = \frac{17.0\ \text{W}}{}\left|\frac{1.728\times10^{5}\text{s}}{}\right|\left|\frac{\text{J}}{\text{W-s}}\right| = 2.93\times10^{6}\ \text{J}$$

$$m = \frac{W}{ed} = \frac{2.93\times10^{6}\ \text{J}}{}\left|\frac{\text{kg}}{4.32\times10^{5}\ \text{J}}\right| = \boxed{6.79\ \text{kg}\,(15.0\ \text{lb}_{\text{m}})}.$$

Discussion

The mass of batteries required for this application is fairly large due to the low *COP* of the thermoelectric cooler. Further, the relatively large amount of heat that must be rejected to the ambient (also the result of the low *COP*) will lead to a large heat exchanger. The thermoelectric cooler may not be ideal for this application.

1.3 Problem Solving Methodology

Engineering is all about problem solving. As an engineer you should be one of the best problem solvers in any group of people. One objective of this text is to provide you with a lot of practice solving engineering problems. Heat transfer provides a great opportunity to tackle some very relevant and interesting problems. To this end, it is important to develop a general problem solving approach that can be systematically used to solve problems in this course as well as in any engineering discipline. The steps that we suggest are laid out below.

1. *Sketch the problem and list known values.* The problem statement will provide information about the problem and include important quantities that must be taken as inputs to the problem solution. It is best to draw a sketch that represents the problem and label these known quantities on the sketch. It is usually a good idea to convert these known values to a self-consistent unit system so that the solution is not complicated by unit conversions.
2. *List assumptions.* Engineering analysis almost always involves simplifying a complex problem so that it can be analyzed and understood. This process requires that you make assumptions and these assumptions should be carefully listed so that the limitations of the solution are clearly established. Some key assumptions may be included in the problem statement. However, it may be necessary for you to make additional assumptions and these often must be justified with appropriate calculations.
3. *Analysis*. Once the inputs and assumptions are clearly laid out, it is necessary to carry out an analysis. The analysis procedure will require that you apply generally useful tools such as energy balances, mass balances, rate equations, property information, etc., to the specific problem being examined. It is almost always advisable to draw additional sketches showing the system being analyzed (for energy balances), the geometric quantities of interest, the energy flows being calculated, etc. The analysis will lead to the systematic identification of a system of equations that can be used to solve the problem. The system of equations should be checked for completeness.
4. *Solution*. The system of equations derived in the analysis must be solved to provide useful numerical answers. First, examine the equations and identify a solution strategy. Can they be solved sequentially and explicitly? Is iteration required? If so, how will the iteration process be accomplished? The answer to these questions together with the intended purpose of the analysis will dictate the solution technique that is adopted. If your ultimate goal is to carry out a parametric study and generate a plot then you will eventually need to solve the equations using some computer software tool. In some cases it is sufficient to solve the equations using pencil, paper, and calculator. In either case, the analysis step that involves deriving a complete set of equations should be carried out *separately from and prior to* the solution step, in which these equations are solved. There is only one correct set of equations, but there are many equally correct methods that can be used to solve these equations.
5. *Discussion/Exploration*. This step is the most challenging and interesting one. Examine your solution and present any important conclusions that can be drawn. What is important in the problem? What is not so

important? Manipulate your solution to identify interesting trends and explain them. Carry out simple sanity checks or thought experiments to give you confidence in the solution. If you change an input then how should your solution change? Is this what actually happens? As you solve engineering problems in your career, you will become cognizant of how important it is to be right. Your solutions will guide decisions in design processes that are very costly and it is often expensive to be wrong. Obviously no one is right all the time, but it is usually possible to identify mistakes by careful and critical examination of your solution. The manipulation and exploration of a solution is easier if it is implemented using computer software.

1.4 Heat Transfer Mechanisms

The three mechanisms commonly used to understand and describe heat transfer are discussed in this section. The remainder of the book presents each of these mechanisms in much more detail, but it is useful to introduce the mechanisms and associated rate equations before proceeding.

1.4.1 Conduction

Conduction refers to heat transfer that is a result of the interactions of the micro-scale energy carriers that exist within a material. Conduction is a phenomenon that is conceptually easy to grasp, particularly in a gas or fluid where the energy carriers are typically molecules. Fast moving (i.e., higher temperature) molecules will strike slower moving (i.e., lower temperature) molecules causing an energy transfer from the hot to the cold molecules. This interaction occurs at a molecular level and the aggregated result of all of these individual collisions at the macroscale is the transfer of energy from hot to cold. Energy transfer by conduction is sometimes referred to as **thermal diffusion**. Conduction is the subject of Chapters 2 through 6 of this text.

In some materials the energy carriers may not be molecules, but the diffusion process is basically the same. The energy carriers in a solid may be electrons or phonons (i.e., vibrations in the structure of the solid). The transfer of energy by conduction is still related to the interactions of these microscale energy carriers. More energetic (i.e., higher temperature) energy carriers transfer energy to less energetic (i.e., lower temperature) ones, resulting in a net flow of energy from hot to cold (i.e., heat transfer).

No matter what material and energy carriers are involved, the rate equation that characterizes conduction heat transfer is **Fourier's Law**. Fourier's Law relates the **heat flux** (the heat transfer rate per unit area) in a particular direction to the temperature gradient in that same direction. For example, in the x-direction Fourier's Law can be written as:

$$\dot{q}_x'' = -k\frac{\partial T}{\partial x}, \tag{1.3}$$

where $\dot{q}_x''$ is the heat flux in the x-direction. Note that in this text the $''$ superscript indicates per unit area (just as the $'$ superscript will indicate per unit length and the $'''$ superscript per unit volume). Therefore, the heat flux $\dot{q}_x''$ has units of J/s-m^2 (or W/m^2). The parameter k in Eq. (1.3) is the **thermal conductivity** of the material. Thermal conductivity is a transport property that is discussed in more detail in Section 2.1. Evaluating the units of Eq. (1.3)

$$\underbrace{\left[\frac{\text{W}}{\text{m}^2}\right]}_{\dot{q}_x''} = \underbrace{\left[\frac{\text{W}}{\text{m-K}}\right]}_{k}\underbrace{\left[\frac{\text{K}}{\text{m}}\right]}_{\frac{\partial T}{\partial x}} \tag{1.4}$$

shows that thermal conductivity must have units of [W/m-K]. Transport properties, like thermodynamic properties (e.g., enthalpy or entropy), are fixed once you know the state of the material. In Section 1.5 methods for obtaining transport properties for specific materials are discussed. Table 1.1 provides the range of conductivity values that can be expected for some typical materials.

Fourier's Law makes physical sense in that we know heat must flow from hot to cold. For example, Figure 1.2 illustrates the temperature as a function of one dimension (x) in a stationary substance. This sketch might correspond to the temperature in the wall of a house on a cold winter day; the inner surface is adjacent to the

Table 1.1 Conductivity of typical materials.

Material	Conductivity (W/m-K)
Pure metals	50 to 500
Alloys	5 to 50
Polymers	0.1 to 2
Liquids	0.1 to 1
Gases	0.01 to 0.1

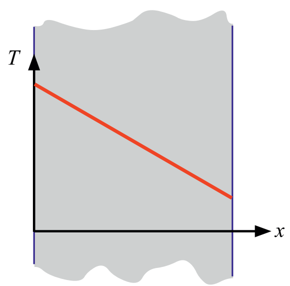

Figure 1.2 A sketch showing temperature as a function of position x.

heated interior of the house and is therefore warmer than the outer surface, which is adjacent to cold outdoor air. Physically, it seems obvious that there is heat transfer from left to right (i.e., from the warm inside of your house to the cold outdoors). Fourier's Law simply expresses this idea mathematically. The temperature is decreasing in the x-direction and therefore the temperature gradient, $\partial T/\partial x$, is negative. The negative sign appearing in Eq. (1.3) results in the rate of heat transfer in the x-direction being positive for this example (i.e., conduction is causing an energy flow from inside to outside).

Fourier's Law is an example of a **rate equation**. In heat transfer, rate equations relate the rate of energy transfer by heat to temperature gradients or temperature differences. Fourier's Law is the rate equation that we will always use for conduction heat transfer and it is also our primary tool for understanding conduction problems.

1.4.2 Convection

Convection refers to heat transfer between a surface and an adjacent flowing fluid as shown in Figure 1.3. Convection is not truly a unique mode of heat transfer. Within the fluid, conduction heat transfer occurs but the situation is complicated substantially by the motion of the fluid itself. The rate equation that characterizes convection heat transfer is **Newton's Law of Cooling**:

$$\dot{q}_{conv} = \bar{h}\,A_s(T_s - T_\infty), \tag{1.5}$$

where A_s is the surface area exposed to the fluid. The surface is at temperature T_s and the fluid has a free stream temperature T_∞. The **free stream temperature** refers to the temperature of fluid far away from the surface, where it has not been affected by the presence of the surface. The parameter $\bar{h}$ in Eq. (1.5) is the average **heat transfer coefficient** associated with the convection problem. Examination of the units in Eq. (1.5)

$$\underbrace{[\mathrm{W}]}_{\dot{q}_{conv}} = \underbrace{\left[\frac{\mathrm{W}}{\mathrm{m}^2\text{-}\mathrm{K}}\right]}_{\bar{h}}\underbrace{\left[\mathrm{m}^2\right]}_{A_s}\underbrace{[\mathrm{K}]}_{(T_s - T_\infty)} \tag{1.6}$$

Table 1.2 Typical values of heat transfer coefficient for some situations.

Situation	Heat transfer coefficient (W/m^2-K)
Natural convection with gases	2 to 10
Natural convection with liquids	10 to 50
Forced convection with gases	10 to 70
Forced convection with liquids	50 to 1,000
Boiling and condensation	500 to 2,500

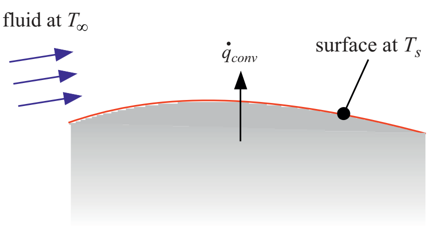

Figure 1.3 Convection.

shows that the average heat transfer coefficient must have units of W/m^2-K. Note that the heat transfer coefficient is *not* a transport or a thermodynamic property like thermal conductivity or density. Rather, $\bar{h}$ is a complex function of the geometry, fluid properties, and flow conditions. Chapters 7 through 11 present some techniques that will allow us to understand and estimate the heat transfer coefficient for a variety of convection situations. Convection is classified as being either forced convection or natural convection. **Forced convection** refers to the situation where the fluid is being externally driven over the surface of interest by, for example, a fan or the wind. **Natural convection** refers to the situation where the fluid motion is driven by buoyancy forces. That is, the fluid that is being heated tends to rise as its density is reduced (or conversely, cooled fluid falls). In the absence of a temperature difference between the surface and the fluid, there would be no fluid motion in a natural convection situation. Typical ranges of values for convective heat transfer coefficients are provided in Table 1.2.

1.4.3 Radiation

Radiation refers to heat transfer between surfaces due to the emission and absorption of electromagnetic waves. Radiation heat transfer is complex when many surfaces at different temperatures are involved and Chapter 14 is dedicated to dealing with this type of problem. However, in the limit that a single surface at temperature T_s interacts only with surroundings at temperature T_{sur}, radiation heat transfer from the surface can be calculated according to:

$$\dot{q}_{rad} = A_s\,\sigma\,\varepsilon\left(T_s^4 - T_{sur}^4\right), \tag{1.7}$$

where A_s is the area of the surface, σ is the Stefan–Boltzmann constant, and ε is the emissivity of the surface. The **Stefan–Boltzmann constant** is a universal constant, $\sigma = 5.67 \times 10^{-8}$ W/m^2-K^4. The **emissivity** is a parameter that ranges between near 0 (for highly reflective surfaces) to near 1 (for highly absorptive surfaces). Note that both T_s and T_{sur} must be expressed in terms of absolute temperature (i.e., in units K rather than °C) in Eq. (1.7). Near room temperature, the rate of radiation heat transfer is often quite small relative to forced convection heat transfer in situations where both phenomena occur simultaneously. However, in natural convection situations where the heat transfer coefficient is small or in a vacuum where convection is nonexistent, radiation can be quite important. Also, Eq. (1.7) shows that the rate of radiation heat transfer increases according to the fourth power of absolute temperature and therefore radiation becomes an important heat transfer mechanism at high temperature.

Example 1.2

A copper pipe carries hot water from a water heater to a shower through the basement of a house. The outer diameter of the pipe is $D = 0.5$ inch and the length of the pipe is $L = 20$ ft. The air in the basement is at $T_\infty = 68°\text{F}$ and the natural convection heat transfer coefficient between the pipe surface and surrounding air is $\bar{h} = 6.8\ \text{W/m}^2\text{-K}$. The pipe radiates to surroundings at the same temperature as the air, $T_{sur} = T_\infty$, and the emissivity of the pipe surface is $\varepsilon = 0.62$. The water enters the pipe at $T_s = 130°\text{F}$. A typical shower requires $Q = 22{,}000$ Btu and takes $time = 10$ minutes.

Determine:

- The rate of heat loss from the pipe.
- The total amount of energy that is lost as the water flows through the pipe during a shower. Compare this value to the total energy required by the shower itself.

Known Values

The problem inputs are listed in the sketch shown in Figure 1.

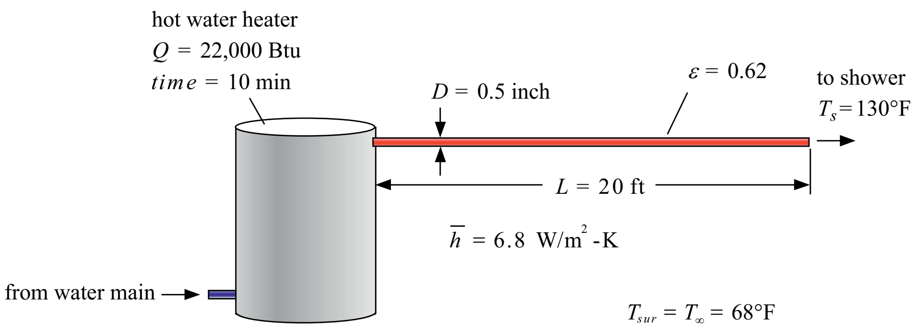

Figure 1 Pipe carrying water for a shower.

Assumptions

- Steady-state conditions exist.
- The water flowing through the pipe does not change temperature substantially as a result of the heat loss from the pipe.
- The surface temperature of the pipe is the same as the temperature of the water in the pipe.
- The energy associated with initially increasing the temperature of the pipe filled with water when the shower starts and then lost as the pipe returns to ambient temperature after the shower is stopped is neglected.

Analysis

The outside surface area of the pipe is:

Continued

Example 1.2 (cont.)

$$A_s = \pi D L. \tag{1}$$

The rate of heat loss by convection is obtained from Newton's Law of Cooling:

$$\dot{q}_{conv} = \bar{h} A_s (T_s - T_\infty). \tag{2}$$

The rate of heat loss by radiation is obtained from Eq. (1.7):

$$\dot{q}_{rad} = A_s \sigma \varepsilon \left(T_s^4 - T_{sur}^4\right). \tag{3}$$

The total rate of heat transfer from the pipe is the sum of the heat losses by radiation and convection:

$$\dot{q}_{loss} = \dot{q}_{conv} + \dot{q}_{rad}. \tag{4}$$

The total amount of energy lost from the pipe during the shower is the time integral of the rate of heat loss, which (assuming steady-state conditions) is:

$$Q_{loss} = \dot{q}_{loss}\, time. \tag{5}$$

Solution

Equations (1) through (5) are explicit and can easily be solved by hand, as was done in Example 1.1. However, in this problem we will use the computer software Engineering Equation Solver (EES) to implement the solution. A tutorial that will allow a new user to become familiar with the EES program can be found in Appendix E.

The inputs to the problem that are listed in Figure 1 are entered in EES.

```
D=0.5 [inch]*Convert(inch,m)                 "diameter"
L=20 [ft]*Convert(ft,m)                      "length"
T_s=ConvertTemp(F,K,130 [F])                 "surface temperature"
T_infinity=ConvertTemp(F,K,68 [F])           "ambient air temperature"
T_sur=T_infinity                             "external temperature for radiation"
h_bar=6.8 [W/m^2-K]                          "heat transfer coefficient"
e=0.62 [-]                                   "emissivity"
Q=22000 [Btu]*Convert(Btu,J)                 "energy associated with shower"
time=10 [min]*Convert(min,s)                 "time associated with shower"
```

Notice that the Convert function in EES was used to convert the units of each variable to its base SI unit; the Convert function returns the unit conversion factor corresponding to the two units provided as arguments. The ConvertTemp function is used to convert the input temperatures from °F to K. Information about unit conversion factors available in EES can be obtained by selecting Unit Conversion Info from the Options menu.

Equations (1) through (5) are entered into the Equations Window. Notice that the constants π and σ are obtained using the built-in constants pi# and sigma# (the # at the end of their name indicates that they are constants in EES, although EES will also accept pi, without the # sign). Information about the constants in EES can be obtained by selecting Constants from the Options menu in EES.

```
A_s=pi#*D*L                                  "surface area of tube"
q_dot_conv=h_bar*A_s*(T_s-T_infinity)        "convection heat transfer rate"
q_dot_rad=sigma#*A_s*e*(T_s^4-T_sur^4)       "radiation heat transfer rate"
q_dot_loss=q_dot_conv+q_dot_rad              "total heat transfer rate"
Q_loss=q_dot_loss*time                       "total energy lost by heat during shower"
```