المجلة الإلكترونية الشاملة متعددة التخصصات
العدد الواحد والستون شهر (٧) ٢٠٢٣

Thermodynamics and Heat Transfer: Simultaneous Heat Transfer Mechanisms and One-Dimensional Heat Conduction

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Abstract

Thermodynamics deals with the amount of heat transfer as a system undergoes a process from one state of equilibrium to another, and does not indicate how long the process will take. But in engineering, we're often concerned with heat transfer rate, which is the subject of heat transfer science. We begin this paper by reviewing the basic concepts of thermodynamics that frame heat transfer. We introduce three basic heat transfer mechanisms, namely conduction, convection, and radiation, and then discuss thermal conduction. This research discusses the basic principles of heat transfer, presenting a wealth of real-world engineering examples to give an idea of how heat transfer can be applied in engineering practice to develop an intuitive understanding of heat transfer by emphasizing physics and physical arguments.

Key words: Thermodynamics, Heat Transfer, Heat Transfer Mechanisms, One-Dimensional Heat Conduction

1. Introduction

Heat and mass transfer is a fundamental science that deals with the rate of transfer of thermal energy. It has a wide application field ranging from biological systems to common household appliances, residential and commercial buildings, industrial processes, electronic devices and food processing. There are three basic heat transfer mechanisms, namely conduction, convection and radiation, the focus of this paper will be on heat conduction. Conduction is the transfer of energy from more energetic particles of a substance to neighboring, less energetic particles as a result of particle interactions. Convection is a mechanism of heat transmission that involves the combined actions of conduction and fluid motion between a solid surface and a moving liquid or gas. Radiation is the energy emitted by matter in the form of electromagnetic waves (or photons) as the electronic configurations of atoms or molecules change. This paper focuses on covering the basic principles of heat transfer, presenting a wealth of real-world engineering examples to give an idea of how heat transfer can be applied in engineering practice to develop an intuitive understanding of heat transfer by emphasizing physics and physical arguments [1].

2. Thermodynamics and Heat Transfer

We've all seen how a cold canned drink left in a room heats up and a warm canned drink kept in the fridge cools down. This is done by the transfer of energy from the heated to the cold medium. The energy transfer always occurs from the higher temperature medium to the lower temperature medium, and it terminates when the two mediums reach the same temperature.

You'll recall from thermodynamics that energy comes in a variety of ways. We are primarily concerned in this work with heat, which is a type of energy that may be transmitted from one system to another as a result of a temperature differential. Heat transfer is the science that deals with determining the rates of such energy exchanges.

You may be asking why we need to do such a thorough investigation of heat transport. After all, a thermodynamic analysis can calculate the quantity of heat transfer for any system going through any process. The reason for this is because thermodynamics is concerned with the amount of heat transfer when a system moves from one equilibrium state to another, and it provides no indication of how long the process will take. A thermodynamic analysis simply informs us how much heat must be transported to achieve a specific change of state in order to meet the principle of conservation of energy.

In practice, the rate of heat transmission (heat transfer per unit time) is more important than the amount of it. A thermodynamic study, for example, may quantify the amount of heat transmitted from a thermos bottle when the hot coffee inside cools from 90°C to 80°C. However, the average user or designer of a thermos bottle is primarily concerned with how long it will take for the hot coffee inside to drop to 80°C, and a thermodynamic study cannot provide a solution to this issue. The issue of heat transfer is determining the rates of heat transfer to or from a system and hence the periods of heating or cooling, as well as the temperature fluctuation (Fig. 1) [2].

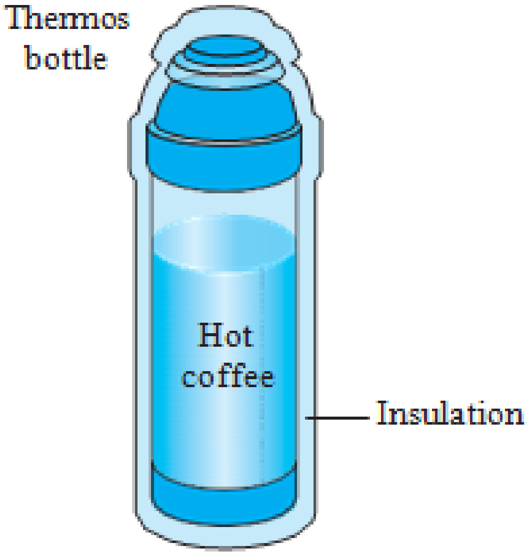


Figure 1: We are normally interested in how long it takes for the hot coffee in a thermos bottle to cool to a certain temperature, which cannot be determined from a thermodynamic analysis alone.

Thermodynamics is concerned with equilibrium states and the transition from one equilibrium state to another. Heat transfer, on the other hand, is a nonequilibrium phenomenon since it works with systems that lack thermal equilibrium. As a result, the study of heat transport cannot be based only on thermodynamic principles. The rules of thermodynamics, on the other hand, serve as the foundation for the study of heat transmission. The first law states that the rate of energy transfer into a system must be equal to the rate of energy increase in that system. According to the second law, heat must be transmitted in the direction of decreasing temperature (Fig. 2). When the brakes are removed, an automobile stopped on an inclined road must travel downward in the direction of decreasing height. It is also equivalent to an electric current flowing in the opposite direction of decreasing voltage or a fluid moving in the opposite direction of decreasing total pressure [3].

The presence of a temperature differential is the most basic prerequisite for heat transmission. Net heat transmission between two bodies at the same temperature is impossible. The driving force for heat transfer is temperature difference, just as voltage difference is the driving force for electric current flow and pressure difference is the driving force for fluid flow. The size of the temperature gradient (the temperature difference per unit length or the rate of change of temperature) in that direction determines the rate of heat transfer in that direction. The larger the temperature gradient, the higher the rate of heat transfer.

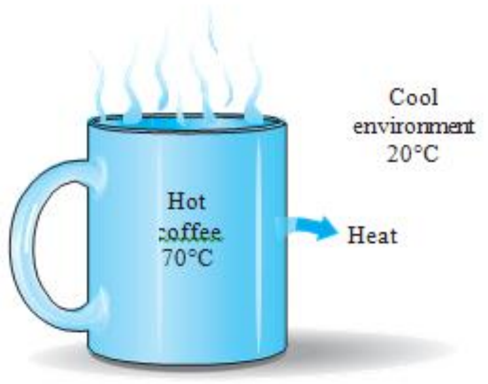


Figure 2: Heat flows in the direction of decreasing temperature.

Application Areas of Heat Transfer

Heat transfer is widely encountered in engineering systems and other elements of life, and certain application areas of heat transfer are not far away. In reality, there is no need to travel anyplace. Human comfort is intimately related to the pace at which the human body rejects heat to its environment. We try to manage this heat transmission rate by altering our apparel to the weather. Many common household gadgets are developed, in whole or in part, utilizing heat transfer principles. The electric or gas stove, the heating and air conditioning system, the refrigerator and freezer, the water heater, the iron, and even the computer, TV, and DVD player are some examples. Of course, energy-efficient homes are built with the goal of limiting heat loss in the winter and gain in the summer. Many other systems, such as vehicle radiators, solar collectors, different components of power plants, and even spacecraft, rely heavily on heat transport (Fig. 1-3). The ideal insulation thickness in home walls and roofs, hot water or steam pipes, or water heaters is established using a heat transfer study with economic consideration [4].

Historical Background

Heat has always been seen as something that causes us to feel warm, and one would believe that the nature of heat was one of the first things that humans comprehended. However, it wasn't until the middle of the nineteenth century that we had a full physical understanding of the nature of heat, due to the development of the kinetic theory at the time, which sees molecules as small balls in motion with kinetic energy. The energy associated with the random motion of atoms and molecules is thus defined as heat. Although it was proposed in the eighteenth and early nineteenth centuries that heat is the manifestation of molecular motion (called the live force), the dominant view of heat until the middle of the nineteenth century was based on the caloric theory proposed in 1789 by the French chemist Antoine Lavoisier (1743-1794). According to the caloric hypothesis, heat is a fluid-like material called the caloric, which is massless, colorless, odorless, and tasteless and may be poured from one body into another (Fig. 3). When calories were supplied to a body, it increased in temperature; when caloric was taken from a body, it reduced in temperature.

When a body couldn't hold any more caloric, it was considered to be saturated with caloric, just like when a glass of water couldn't dissolve any more salt or sugar. This interpretation resulted in the words saturated liquid and saturated vapor, which are still used today.

Soon after its debut, the caloric hypothesis was challenged. It asserted that heat is a non-creatable and non-destructible material. However, it was recognized that heat could be created forever by rubbing one's hands or two pieces of wood together. In his studies published in 1798, the American Benjamin Thompson (Count Rumford) (1753-1814) demonstrated that heat may be created continually by friction. Several other people questioned the caloric theory's validity. However, it was the painstaking investigations of the Englishman James P. Joule published in 1843 that eventually convinced the doubters that heat was not, after all, a substance, and so laid the caloric theory to rest. Although the caloric theory was abandoned by the middle of the nineteenth century, it made significant contributions to the development of thermodynamics and heat transmission [5].

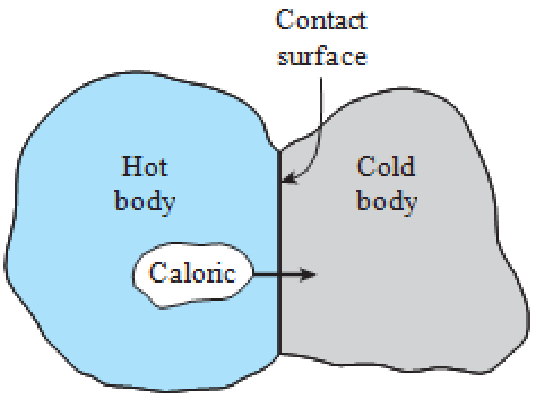


Figure 3: In the early nineteenth century, heat

3. Heat Transfer Mechanisms

Thermodynamic analysis is concerned with the amount of heat transfer as a system undergoes a process from one state of equilibrium to another. The science that deals with determining the rates of this energy transfer is heat transfer. Heat transfer always occurs from the higher-temperature medium to the lower-temperature medium and heat transfer ceases when the two mediums reach the same temperature. Heat may be transmitted in three ways: conduction, convection, and radiation. All forms of heat transfer require a temperature differential to exist, and all modes are from a high-temperature medium to a lower-temperature medium. Each method is described in detail below [6].

3.1 Conduction

Conduction is the transfer of energy from more energetic particles of a substance to nearby less energetic particles as a result of particle interactions. Conduction may occur in solids, liquids, and gases. Conduction occurs in gases and liquids due to the collisions and diffusion of molecules during their random motion. It is caused by the combination of vibrations of molecules in a lattice and energy transit by free electrons in materials. A cold canned drink in a warm environment, for example, ultimately heats up to room temperature due to heat transfer from the room to the drink via conduction through the metal can. The rate of heat conduction across a medium is determined by its shape, thickness, and material, as well as the temperature differential across the medium. Wrapping a hot water tank in glass wool (an insulating material) lowers the rate of heat loss from the tank. The lower the heat loss, the thicker the insulation, we also know that when the temperature of the area holding the tank is reduced, a hot water tank loses heat at a faster pace, furthermore, the larger the tank, the greater the surface area and, as a result, the rate of heat loss [7].

Consider steady heat conduction through a large plane wall of thickness $\Delta x = L$ and area A, as shown in Fig.4. The temperature difference across the wall is $\Delta T = T_2 - T_1$. Experiments have shown that the rate of heat transfer $\dot{Q}$ through the wall is *doubled* when the temperature difference ΔT across the wall or the area A normal to the direction of heat transfer is doubled, but is *halved* when the wall thickness L is doubled.

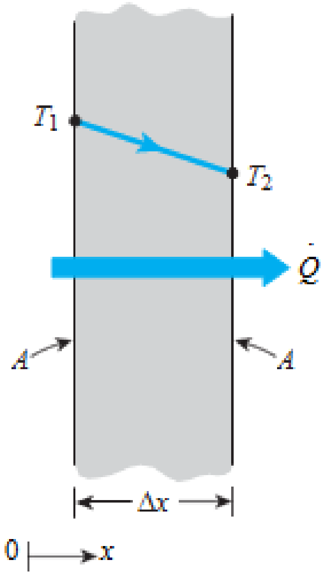


Figure 4: Heat conduction through a large plane wall of thickness Dx and area A.

As a result, the rate of heat conduction across a plane layer is proportional to the temperature difference across the layer and the heat transfer area, but inversely proportional to the layer thickness. That is,

Rate of heat conduction = (Area)(Temperature difference) / Thickness

$$q = K.A. (\Delta T / \Delta X) \quad (1)$$

where the constant of proportionality k is the thermal conductivity of the material

We have seen that different materials store heat differently, and we have defined the property specific heat c_p as a measure of a material’s ability to store thermal energy. For example, c_p – 4.18 kJ/kg·°C for water and c_p= 0.45 kJ/kg·°C for iron at room temperature, which indicates that water can store almost 10 times the energy that iron can per unit mass. Likewise, the thermal conductivity k is a measure of a material’s ability to conduct heat. For example, k = 0.607 W/m·K for water and k = 80.2 W/m·K for iron at room temperature, which indicates that iron conducts heat more than 100 times faster than water can. Thus we say that water is a poor heat conductor relative to iron, although water is an excellent medium to store thermal energy [8].

The defining equation for thermal conductivity is Equation 1 for the rate of conduction heat transfer under steady-state circumstances. Thus, a material's thermal conductivity may be defined as the rate of heat transfer per unit area per unit temperature difference across a unit thickness of the material. A material's thermal conductivity is a measurement of its capacity to conduct heat. A high thermal conductivity value suggests an excellent heat conductor, whereas a low number indicates a poor heat conductor or insulator. Table 1 shows the thermal conductivities of various common materials at room temperature.

Table 1: The thermal conductivities of some materials at room temperature

Material	***k*, W/m·K***
Diamond	2300
Silver	429
Copper	401
Gold	317
Aluminum	237
Iron	80.2
Mercury (l)	8.54
Glass	0.78
Brick	0.72
Water (l)	0.607
Human skin	0.37
Wood (oak)	0.17
Helium (g)	0.152
Soft rubber	0.13
Glass fiber	0.043
Air (g)	0.026
Urethane, rigid foam	0.026

*** Multiply by 0.5778 to convert to Btu/h·ft·°F.**

The thermal conductivity of pure copper at room temperature is $k = 401$ W/m·K, which indicates that a 1-m-thick copper wall will conduct heat at a rate of 401 W per m^2 area per K temperature difference across the wall. It is worth noting that materials with high thermal conductivity, such as copper and silver, are also strong electric conductors. Rubber, wood, and Styrofoam are poor heat conductors and have low conductivity ratings.

An electric resistance heater with a defined output can be used to heat a layer of material with specified thickness and area from one side. All of the heat generated by the resistance heater will be passed via the material whose conductivity is to be assessed if the exterior surfaces of the heater are adequately insulated. The thermal conductivity is then calculated by taking the two surface temperatures of the material when constant heat transfer is achieved and plugging them into Eq. 1 along with other known parameters (Fig 5) [8].

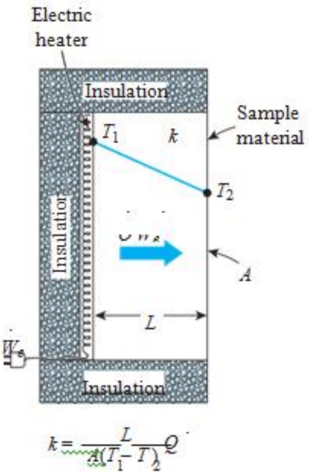


Figure 6: A simple experimental setup to determine the thermal conductivity

The thermal conductivities of materials vary over a wide range, as shown in Fig. 6.

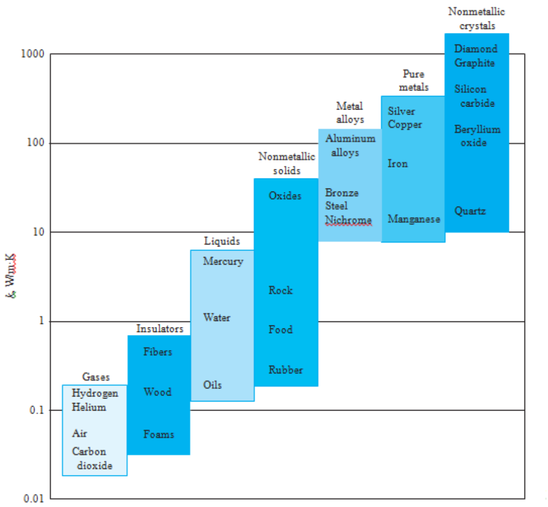


Figure 7: The range of thermal conductivity of various materials at room temperature.

Thermal conductivities of gases like air differ by a factor of 104 from those of pure metals like copper. The highest thermal conductivities are found in pure crystals and metals, whereas the lowest are found in gases and insulating materials. Temperature is a measure of the kinetic energy of particles in a material, such as molecules or atoms. The kinetic energy of molecules in a liquid or gas is owing to their random translational motion as well as their vibrational and rotational movements. When two molecules with different kinetic energies collide, some of the kinetic energy of the more energetic (higher-temperature) molecule is transferred to the less energetic (lower-temperature) molecule, similar to how part of the kinetic energy of the faster ball is transferred to the slower one when two elastic balls of the same mass collide at different velocities. The greater the temperature, the quicker the molecules travel, the more collisions there are, and the better the heat transmission.

The thermal conductivity of gases is proportional to the square root of the thermodynamic temperature T and inversely proportional to the square root of the molar mass M, according to the kinetic theory of gases and confirmed by tests. As a result, for a given gas (fixed M), rising temperature increases thermal conductivity, whereas decreasing temperature increases thermal conductivity. For example, at a constant temperature of 1000 K, the thermal conductivity of helium (M 54) is 0.343 W/m•K, whereas that of air (M = 29) is 0.0667 W/m•K, which is significantly lower than that of helium [7].

They can, however, be employed at pressures other than 1 atm since the thermal conductivity of gases is pressure independent across a wide range of pressures seen in reality. Heat conduction in a liquid is hampered by the fact that the molecules are closer together and exert a greater intermolecular force field. Liquids' thermal conductivities are typically between those of solids and gases. A substance's thermal conductivity is generally greatest in the solid phase and lowest in the gas phase. Except around the thermodynamic critical point, liquid thermal conductivity is largely indifferent to pressure. Unlike gases, most liquids' thermal conductivities decrease with increasing temperature, with water being an exception. The conductivity of liquids, like that of gases, diminishes with increasing molar mass. Liquid metals with high thermal conductivities, such as mercury and sodium, are ideal for use in applications requiring a high heat transfer rate to a liquid, such as nuclear power plants.

Heat conduction occurs in solids owing to two effects: lattice vibrational waves caused by the vibrational movements of molecules arranged in a periodic pattern termed a lattice, and energy carried by the free flow of electrons in the solid (Fig. 7). A solid's thermal conductivity is calculated by combining its lattice and electronic components. The electrical component is principally responsible for pure metals' relatively high thermal conductivities. The lattice component of thermal conductivity is highly dependent on the arrangement of the molecules. Diamond, for example, is a highly organized crystalline solid with the highest known thermal conductivity at ambient temperature [2].

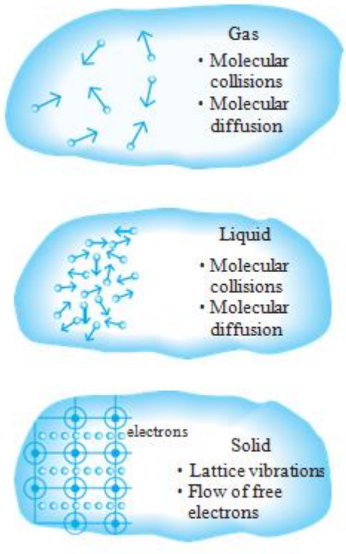


Figure 8: The mechanisms of heat conduction in different phases of a substance.

In contrast to metals, which are both strong electrical and heat conductors, crystalline solids like diamond and semiconductors like silicon are both good heat conductors but poor electrical conductors. As a result, these materials are widely used in the electronics sector. Diamond heat sinks, despite their increased cost, are utilized to cool sensitive electronic components due to their exceptional thermal conductivity. Silicon oils and gaskets are widely utilized in electronic component packaging because they provide both good thermal contact and strong electrical isolation. Pure metals have strong thermal conductivities, and one would expect metal alloys to have similar conductivities. An alloy composed of two metals with thermal conductivities k1 and k2 should have a conductivity k between k1 and k2. This, however, does not appear to be the case. The thermal conductivity of a two-metal alloy is often significantly lower than that of either metal. Even little concentrations of "foreign" molecules that are strong conductors themselves in a pure metal substantially impair heat transport in that metal. For example, the thermal conductivity of steel having only 1% chrome is 62 W/m•K, but the thermal conductivities of iron and chromium are 83 and 83, respectively [8].

Material thermal conductivities change with temperature. Thermal conductivity varies significantly across temperature ranges for certain materials but not for others. When temperatures reach absolute zero, the thermal conductivities of some materials increase dramatically, and these substances become superconductors. Copper, for example, has a maximum conductivity of roughly 20,000 W/m•K at 20 K, which is nearly 50 times the conductivity at ambient temperature. Physical dimensions in certain new fields of technology, such as microelectronics, are often in the micro or nanometer range. The modest physical dimensions of these applications will most likely impact the value of heat conductivity in the solid and liquid phases. In these cases, as the physical dimensions shrink, the average net distance traveled by the energy carriers shrinks, lowering the value of thermal conductivity.

The temperature dependency of thermal conductivity complicates conduction analysis significantly. As a result, it is usual practice to calculate the thermal conductivity k at the average temperature and regard it as a constant [3].

A material is typically considered to be isotropic in heat transfer analysis, that is, to have uniform characteristics in all directions. This assumption is reasonable for most materials, with the exception of laminated composite materials and wood, which have differing structural properties in various orientations. The heat conductivity of wood, for example, differs from that of wood parallel to the grain.

3.2 Convection

Convection is a mechanism of energy transmission between a solid surface and a moving liquid or gas, involving the combined effects of conduction and fluid motion. The higher the convective heat transfer, the quicker the fluid velocity. Heat transmission between a solid surface and the neighboring fluid occurs only by conduction in the absence of any bulk fluid motion. The existence of fluid bulk motion improves heat transmission between the solid surface and the fluid, but it also complicates determining heat transfer rates.

Conduction initially transfers heat to the air layer next to the block. This heat is then carried away from the surface by convection, which is caused by a combination of conduction within the air caused by random motion of air molecules and bulk or macroscopic motion of the air, which removes the heated air near the surface and replaces it with cooler air (Fig. 1-8).

Convection is called forced convection if the fluid is forced to flow over the surface by external means such as a fan, pump, or wind. Natural (or free) convection, on the other hand, refers to fluid motion generated by buoyancy forces caused by density differences caused by temperature variations in the fluid (Fig. 1-9). In the absence of a fan, for example, heat transfer from the surface of the hot block in Fig. 1-8 is by natural convection because any motion in the air is caused by the rise of the warmer (and thus lighter) air near the surface and the fall of the cooler (and thus heavier) air to fill its place. If the temperature differential between the air and the block is not big enough to overcome the resistance of air to movement and so generate natural convection currents, heat transfer between the block and the surrounding air occurs by conduction [8].

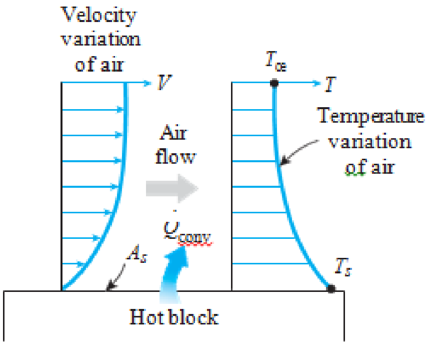


Figure 9: Heat transfer from a hot surface to air by convection.

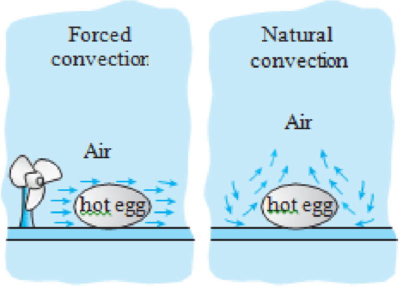


Figure 10: The cooling of a boiled egg by forced and natural convection.

Heat transfer processes that entail a change in phase of a fluid, such as the rise of vapor bubbles during boiling or the fall of liquid droplets during condensation, are also called convection because of the fluid motion created throughout the process. Despite the complexities of convection, the rate of convection heat transfer is seen to be proportional to the temperature differential, as described easily by Newton's equation of cooling.

$$Q_{\text{conv}} = hA_s\,(T_s - T_\infty) \qquad \text{(W)} \qquad \textbf{(2)}$$

where h is the *convection heat transfer coefficient* in W/m^2·K or Btu/h·ft^2·°F, A_s is the surface area through which convection heat transfer takes place, T_s is the surface temperature, and T_∞ is the temperature of the fluid sufficiently far from the surface. Note that at the surface, the fluid temperature equals the surface temperature of the solid.

The convection heat transfer coefficient h is not a fluid characteristic. It is an empirically measured parameter whose value is determined by all of the elements impacting convection, such as surface shape, fluid motion, fluid characteristics, and bulk fluid velocity. Some individuals believe that convection is not a basic heat transmission method because it is simply heat conduction in the presence of fluid motion. But we still need to give this combined phenomenon a name, unless we want to keep referring to it as "conduction with fluid motion." Despite significant arguments to the contrary, it is practical to identify convection as a separate heat transport process [3].

3.3 Radiation

Radiation is the energy emitted by matter in the form of electromagnetic waves (or photons) as the electronic configurations of atoms or molecules change. Heat transmission through radiation, unlike conduction and convection, does not need the existence of an intervening medium. In reality, in a vacuum, heat transmission through radiation is the quickest (at the speed of light) and suffers no attenuation. This is how the sun's energy reaches the planet. Thermal radiation, which is the type of radiation released by substances as a result of their temperature, is of particular relevance in heat transfer investigations. It is distinct from other types of electromagnetic radiation including x-rays, gamma rays, microwaves, radio waves, and television waves. Thermal radiation is emitted by all bodies at temperatures above absolute zero. Radiation is a volumetric phenomenon, and all solids, liquids, and gases, to variable degrees, emit, absorb, or transmit radiation. However, for solids that are opaque to thermal radiation, such as metals, wood, and rocks, radiation is usually considered to be a surface phenomenon because the radiation emitted by the interior regions of such materials can never reach the surface, and the radiation incident on such bodies is usually absorbed within a few microns of the surface. The Stefan-Boltzmann law gives the maximum rate of radiation that may be emitted from a surface at a thermodynamic temperature Ts (in K or R) as

where $\sigma = 5.670*10^{-8}$ W/m^2·K^4 or 0.1714 *10^{-8} Btu/h·ft^2·R^4 is the *Stefan–Boltzmann constant.* The idealized surface that emits radiation at this maximum rate is called a **blackbody**, and the radiation emitted by a blackbody is called **blackbody radiation**. The radiation emitted by all real surfaces is less than the radiation emitted by a blackbody at the same temperature, and is expressed as

$$Q_{\text{emit}} = \varepsilon \sigma A_s T^4_s \text{ (W)} \quad \textbf{(3)}$$

where ε is the **emissivity** of the surface. The property emissivity, whose value is in the range $0 \le \varepsilon \le 1$, is a measure of how closely a surface approximates a blackbody for which $\varepsilon = 1$.

Another important radiation property of a surface is its **absorptivity** a, which is the fraction of the radiation energy incident on a surface that is absorbed by the surface. Like emissivity, its value is in the range $0 \le \alpha \le 1$. A blackbody absorbs the entire radiation incident on it. That is, a blackbody is a perfect absorber (α=1) as it is a perfect emitter.

In general, both ε and α of a surface depend on the temperature and the wavelength of the radiation. **Kirchhoff's law** of radiation states that the emissivity and the absorptivity of a surface at a given temperature and wavelength are equal. In many practical applications, the surface temperature and the temperature of the source of incident radiation are of the same order of magnitude, and the average absorptivity of a surface is taken to be equal to its average emissivity. The rate at which a surface absorbs radiation is determined from (Fig. 10) [8].

$$Q_{\text{absorbed}} = \alpha\, Q_{\text{incident}} \quad (\text{W}) \quad (4)$$

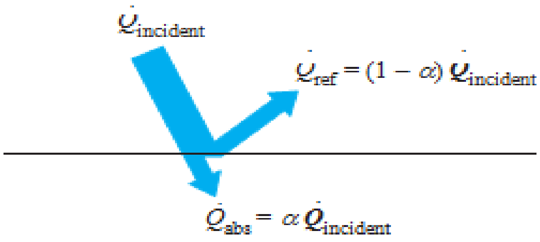


Figure 11: The absorption of radiation incident on an opaque surface of absorptivity

4. Simultaneous Heat Transfer Mechanisms

We stated three heat transport processes, but none of them can exist in the same medium at the same time. Heat transmission, for example, occurs only by conduction in opaque materials, but via conduction and radiation in semitransparent solids. As a result, a solid can have conduction and radiation but not convection. However, heat transmission through convection and/or radiation on a solid's surfaces exposed to a fluid or other surfaces may occur. For example, in a warmer climate, the exterior surfaces of a cold piece of granite will warm up due to heat uptake via convection (from the air) and radiation (from the sun or warmer surrounding surfaces). However, when this heat is transported to the interior area of the rock by conduction, the inner regions of the rock will warm up [7].

Conduction and perhaps radiation transport heat in a static fluid (no bulk fluid motion) and convection and radiation transfer heat in a moving fluid. Heat transmission through a fluid is either conduction or convection in the absence of radiation, depending on the presence of any bulk fluid motion. Convection is a combination of conduction and fluid motion, and conduction in a fluid is a specific instance of convection in the absence of fluid motion (Fig. 11). As a result, when it comes to heat transport through a fluid, we can have either conduction or convection, but not both. Furthermore, gases are nearly transparent to radiation, with the exception of a few gases that are known to absorb radiation substantially at specific wavelengths. Ozone, for example, absorbs a lot of UV energy. However, most of the time, a gas between two solid surfaces does not interfere with radiation and essentially behaves as a vacuum. Liquids, on the other hand, are often powerful radiation absorbers. Finally, because conduction or convection need the existence of a material medium, heat transport across a vacuum happens exclusively through radiation [8].

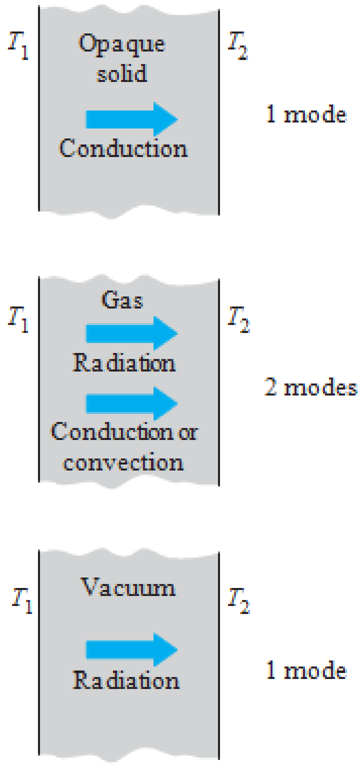
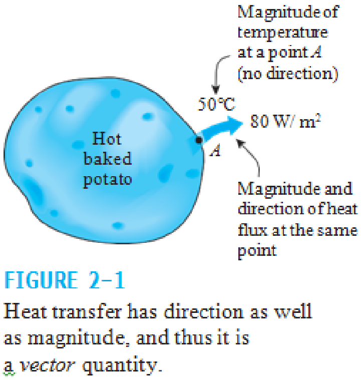


Figure 12: Although there are three mechanisms of heat transfer, a medium may involve only two of them simultaneously

5. One-Dimensional Heat Conduction

Heat conduction was described as the transmission of thermal energy from more energetic particles in a medium to less energetic particles nearby. It was asserted that conduction may occur in liquids, gases, and solids as long as there is no bulk motion. Although heat transmission and temperature are connected, they are not the same thing. Heat transfer, unlike temperature, has both direction and magnitude, making it a vector quantity (Fig. 12). As a result, in order to fully characterize heat transmission at a place, we must define both direction and magnitude. Saying that the temperature on the inner surface of a wall is 18°C, for example, properly conveys the temperature at that point. But saying that the heat flux on that surface is 50 W/m^2 immediately prompts the question “in what direction?” We can answer this question by saying that heat conduction is toward the inside (indicating heat gain) or toward the outside (indicating heat loss) [9].



Heat transfer has direction as well as magnitude, and thus it is a *vector* quantity.

Figure 13: Heat transfer has direction as well as magnitude, and thus it is a vector quantity

We may prevent such issues by using a coordinate system and indicating direction using plus or minus signs. Heat transfer is usually understood to be positive in the positive direction of a coordinate axis and negative in the opposite direction. As a result, a positive quantity indicates positive heat transmission and a negative quantity shows negative heat transfer (Fig. 13).

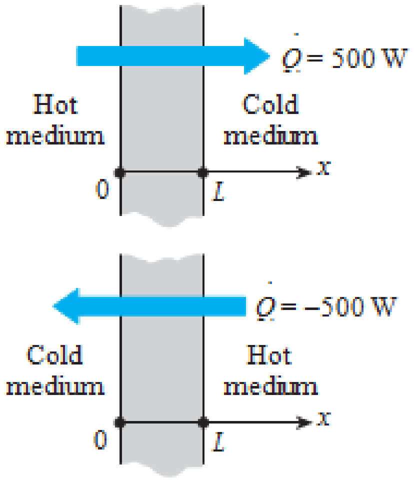
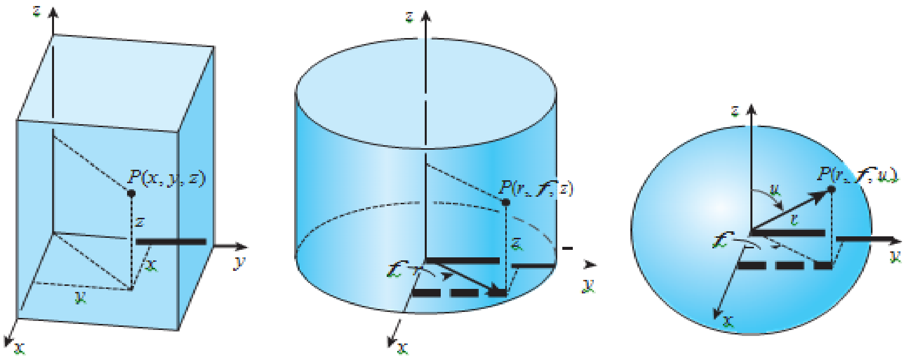


Figure 14: Indicating direction for heat transfer (positive in the positive direction; negative in the negative direction

The temperature differential is the driving factor for all forms of heat transmission, and the bigger the temperature difference, the faster the heat transfer. Some heat transfer problems in engineering necessitate determining the temperature distribution (temperature variation) throughout the medium in order to calculate some quantities of interest such as the local heat transfer rate, thermal expansion, and thermal stress at some critical locations at specific times. The specification of the temperature at a point in a medium necessitates the specification of that point's location first. This can be accomplished by selecting an appropriate coordinate system, such as rectangular, cylindrical, or spherical coordinates, and a handy reference point (the origin), depending on the geometry involved [8].

The *location* of a point is specified as (x, y, z) in rectangular coordinates, as (r, f, z) in cylindrical coordinates, and as (r, f, u) in spherical coordinates, where the distances *x*, *y*, *z*, and *r* and the angles *f* and *u* are as shown in Fig.14. Then the temperature at a point (*x*, *y*, *z*) at time *t* in rectangular coordinates is expressed as *T*(*x*, *y*, *z*, *t*). The best coordinate system for a given geometry is the one that describes the surfaces of the geometry best. For example, a parallelepiped is best described in rectangular coordinates since each surface can be described by a constant value of the *x*-, *y*-, or *z*-coordinates. A cylinder is best suited for cylindrical coordinates since its lateral surface can be described by a constant value of the radius. Similarly, the entire outer surface of a spherical body can best be described by a constant value of the radius in spherical coordinates. For an arbitrarily shaped body, we normally use rectangular coordinates since it is easier to deal with distances than with angles. The notation just described is also used to identify the variables involved in a heat transfer problem. For example, the notation *T*(*x*, *y*, *z*, *t*) implies that the temperature varies with the space variables *x*, *y*, and *z* as well as time [10].



(a) Rectangular coordinates (b) Cylindrical coordinates (c) Spherical coordinates

Figure 15: The various distances and angles involved when describing the location of a point in different coordinate systems.

The notation $T(x)$, on the other hand, indicates that the temperature varies in the x-direction only and there is no variation with the other two space coordinates or time.

Heat transfer difficulties are frequently characterized as either stable (also known as steadystate) or transient (also known as unsteady). The phrase stable denotes no change with time at any point inside the medium, whereas transient denotes temporal fluctuation or time dependency. As a result, the temperature or heat flux remains constant over time during sustained heat transfer across a medium at any place, even if both values might fluctuate (Fig. 2-4). For example, heat transmission through a house's walls remains constant while the circumstances within and outside stay constant for several hours. Even yet, unless the temperatures inside and outside the home are the same, the temperatures on the inner and exterior sides of the wall will be different. In contrast, chilling an apple in a refrigerator is a transient heat transfer process since the temperature at any fixed spot within the fruit changes over time. Temperature generally fluctuates with time and place during transient heat transfer. The temperature of the medium varies evenly with time in the particular situation of fluctuation with time but not with position. These heat transmission systems are referred to be lumped systems. During a heating or cooling operation, a tiny metal item, such as a thermocouple junction or a thin copper wire, can be examined as a lumped system [9].

Most heat transfer issues encountered in practice are transitory in nature, but they are frequently evaluated under some assumed stable circumstances since steady processes are easier to understand and give us with solutions. Heat transmission through the walls and ceiling of a conventional house, for example, is never constant since exterior factors such as temperature, wind speed and direction, sun location, and so on fluctuate frequently. The conditions in a typical residence are not much better. If the goal of a heat transfer analysis of a house is to determine the proper size of a heater, which is usually the case, we need to know the maximum rate of heat loss from the house, which is determined by taking into account the heat loss from the house under worst conditions for an extended period of time, that is, during steady operation under worst conditions. As a result, we may get the answer to our query by doing a heat transfer study under steady-state circumstances. If the heater is big enough to keep the house warm in the most extreme situations, its big enough for anything. Consider heat conduction through a large plane wall, such as a house wall, the glass of a single pane window, the metal plate at the bottom of a pressing iron, a cast-iron steam pipe, a cylindrical nuclear fuel element, an electrical resistance wire, the wall of a spherical container, or a quenched or tempered spherical metal ball. Heat conduction in these and other geometry may be approximated as one-dimensional because heat conduction is strong in one direction and insignificant in others. The one-dimensional heat conduction equation is then developed in rectangular, cylindrical, and spherical dimensions [10].

6. Conclusion

In this research, the basics of heat transfer are introduced and discussed. The science of thermodynamics is concerned with the amount of heat transfer that occurs as a system transitions from one equilibrium state to another, whereas the science of heat transfer is concerned with the rate of heat transfer, which is the primary focus of interest in the design and evaluation of heat transfer equipment. Total energy is the sum of all kinds of energy in a system, which includes internal, kinetic, and potential energies. Internal energy reflects a system's molecular energy and is composed of sensible, latent, chemical, and nuclear forms. Heat or thermal energy is the movement of perceptible and latent forms of internal energy from one medium to another as a result of a temperature difference. As a result of a temperature differential, heat transfer is defined as the exchange of sensible and latent forms of internal energy between two materials. The heat transfer rate, indicated by Q •, is the quantity of heat transmitted per unit time. Heat flux, q •, is the rate of heat transfer per unit area. A closed system is one with a fixed mass, whereas an open system or control volume is one with mass transfer across its limits.

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