专业英语系列教材

English Textbook for College Students Majoring in Power Engineering

能源与动力工程专业英语

主　编　陈冬林
副主编　李　立

华中科技大学出版社
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主　编　陈冬林

副主编　李　立

编　者　顾小松　申忠利

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中国·武汉

内容提要

本书由作者通过收集国外能源与动力工程领域的最新技术资料，并在总结多年专业英语教学经验的基础上编写而成。全书由热工理论基础、燃料及燃烧理论、火力发电厂热力设备及运行、热交换理论及换热器技术、新能源、内燃料机、供热通风及空气调节、热工过程控制等内容组成。全书共有12章，每章由数个单元组成，而每个单元则包含课文、词汇表、难句注释、问答题以及翻译。

本书有较强的知识性和实用性，可作为高等院校能源与动力工程类、建筑环境与设备工程类、热工自动化类以及相关专业本科生和研究生的专业英语教材，也可供从事相关专业的工程技术人员参考。

前　言

近年来，我国国民经济持续快速增长，为了建设能源节约型和环境友好型社会，人们对实现可持续的能源开发与电力生产提出了更高的要求，并促使能源与电力部门大量应用最新技术和设备，为此，有相当一部分先进技术与设备需要在全球范围内进行招标选优。显然，在这种新的形势下，我国需要大量既精通能源与电力生产及设备专业技术，又具有用英语进行专业技术交流与沟通能力的高级专业技术人才。此书正是在此背景下组织编写而成，它适用于能源与动力工程相关专业的在校大学生及广大科技工作者。通过精读与泛读此书，可以使读者直接掌握并熟练应用能源与动力工程技术领域中最常用的专业词汇、特有的语法现象、学术论文的写作风格及翻译技巧，并从中领悟专业英语与普通英语文献的差异与共同点，从而全面提升读者的专业英语阅读、写作、听说交流能力。

本书作者通过查阅众多国内外最新专业权威期刊、国外经典文献及厂家资料，根据多年教学实践对本书内容进行了精心选材和编排，并配置了大量精美的图表。本书主要内容包括：热工理论基础、燃料及燃烧理论、火力发电厂热力设备及运行、热交换理论及换热器技术、新能源、内燃料机、供热通风与空气调节、热工自动控制及其应用等。该书从取材上力图既为在校大学生提供原汁原味的专业英语知识与素材，也为广大一线从事能源与动力工程的科技工作者提供题材广泛、内容新颖的专业文献参考。

本书具有实用性和前沿性的特点。如第3～7章全面地介绍了火力发电厂的生产工艺流程、火力发电厂主设备——锅炉、汽轮机及相关辅助设备的结构特点、工作原理和运行技术等；第9章特别突出了新能源概念及其应用，并重点介绍了零污染排放的太阳能技术、生物质能技术、风能技术及潮汐能技术；针对目前建筑能耗所占的比重越来越大以及人们对高品质空气环境的追求，第11章介绍了商业建筑中央空调制冷系统及相关技术；本书第12章除介绍热工过程控制的基本理论及应用外，还特别对DCS的发展、协调控制、燃烧控制、三冲量汽包水位控制的原理及应用进行了介绍。

全书共由12章组成，其中，陈冬林编写了第2、9、10章，李立编写了第3～7章，顾小松编写了第1、8、11章，申忠利编写了第12章。

本书编写过程中，得到了华中科技大学出版社杨鸥老师、刘平老师的悉心指导与各方面的帮助，在此，表示衷心地感谢。由于篇幅有限，要想全书内容既广泛涵盖能源与动力工程专业知识，又充分体现出英语教学的特点，是很不容易的。我们的编写是一个不断学习、不断积累的过程。由于作者水平有限，不当和错误在所难免，敬请广大读者批评指正。

Contents

Chapter 1 Thermodynamics, Heat Transfer and Fundamentals of Fluid

1.1 Thermodynamics

During a typical day, everyone deals with various engineering systems such as automobiles, refrigerators, microwaves, and dishwashers. Each engineering system consists of several components, and a system's optimal performance depends on each individual component's performance and interaction with other components. In most cases, the interaction between various components of a system occurs in the form of energy transfer or mass transfer. Thermodynamics is an engineering science that provides governing laws that describe energy transfer from one form to another in an engineering system. In this chapter, the basic laws of thermodynamics and their application for energy conversion systems are covered.

ENERGY AND THE FIRST LAW OF THERMODYNAMICS

In performing engineering thermodynamic analysis, we must define the system under consideration. After properly identifying a thermodynamic system, everything else around the system becomes that system's environment. Of interest to engineers and scientists is the interaction between the system and its environment.

In thermodynamic analysis, systems can either consist of specified matter (controlled mass, CM) or specified space (control volume, CV). In a control-mass system, energy—but not mass—can cross the system boundaries while the system is going through a thermodynamic process. Control-mass systems may be called closed systems because no mass can cross their boundary. On the other hand, in a control volume system—also referred to as an open system—both energy and matter can cross the system boundaries. The shape and size of CVs need not necessarily be constant and fixed; however, in this chapter, we will assume that the CVs with fixed shape and size. Another system that should be defined here is an isolated system, which is a system where no mass or energy crosses its boundaries.

The energy of a system consists of three components: kinetic energy, potential energy, and internal energy. The kinetic and potential energy of a system are macroscopically observable. Internal energy is associated with random and disorganized aspects of molecules of a system and is not directly observable. In thermodynamic analysis of systems, the energy of the whole system can be obtained by adding the individual energy components.

CONSERVATION OF ENERGY—THE FIRST LAW OF THERMODYNAMICS

The First Law of Thermodynamics states that energy is conserved; it cannot be created or destroyed, but can change from one form to another. The energy of a closed system can be expressed as

$$E = me + \frac{mu^2}{2g_2} + \frac{mgz}{g_c} \tag{1-1}$$

Where E is the total energy of the system, e is its internal energy per unit mass, and the last two terms are the kinetic energy and potential energy of the system, respectively. The proportionality constant g_c is defined in the nomenclature. When a system undergoes changes, the energy change within the system can be expressed by a general form of the energy-balance equation:

Energy stored in the system = Energy entering the system − Energy leaving the system + Energy generated in the system (e. g. , chemical reactions)

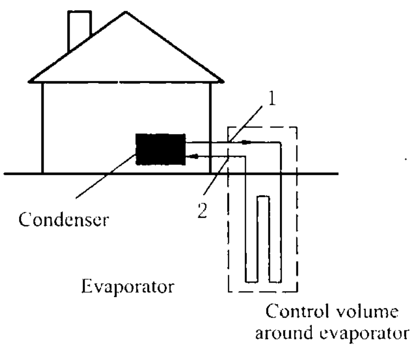

Fig. 1-1 Geothermal-based (ground-source) heat pump

For example, consider the geothermal-based heat pump shown in Fig. 1-1. In this heat pump, a working fluid (R-22, a common refrigerant used with geothermal heat pumps, which is gaseous at room temperature and pressure) is sealed in a closed loop and is used as the transport medium for energy. [1] Fig. 1-2 presents a simple thermodynamic cycle for a heat pump (heating mode) and an associated pressure-enthalpy (p-h) diagram. The saturated vapor and liquid lines are shown in Fig. 1-2, and the region between these two lines is referred to as the wet region, where vapor and liquid coexist. The relative quantities of liquid and vapor in the mixture, known as the quality of the mixture (x), is usually used to denote the state of the mixture. The quality of a mixture is defined as the ratio of the mass of vapor to the mass of the mixture. For example, in 1 kg of mixture with quality x, there are x kg of vapor and $(1-x)$ kg of liquid. Fig. 1-2 shows that the working fluid leaving the evaporator (point 2) has a higher quality than working fluid entering the evaporator (point 1). The working fluid in Fig. 1-2 is circulated through the closed loop and undergoes several phase changes. Within the evaporator, the working fluid absorbs heat from the surroundings (geothermal resource) and is vaporized. The low pressure gas (point 2) is then directed into the compressor, where its

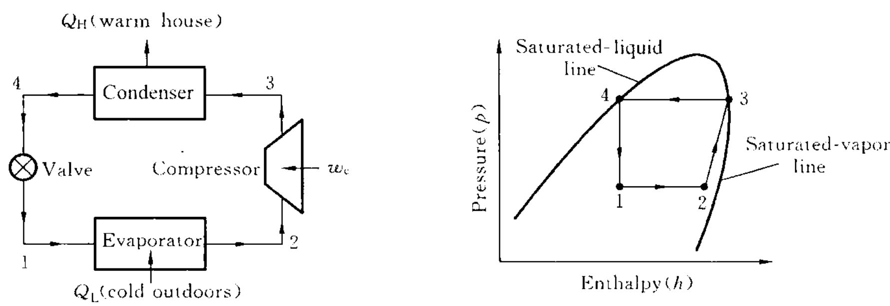

Fig. 1-2 Thermodynamic cycle and p-h diagram for heat pump (heating mode)

pressure and temperature are increased by compression. The hot compressed gas (point 3) is then passed through the condenser, where it loses heat to the surroundings (heating up the house). The cool working fluid exiting the condenser is a high-pressure liquid (point 4), which then passes through an expansion device or valve to reduce its pressure to that of the evaporator (underground loop). [2]

ENTROPY AND THE SECOND LAW OF THERMODYNAMICS

In many events, the state of an isolated system can change in a given direction, whereas the reverse process is impossible. For example, the reaction of oxygen and hydrogen will readily produce water, whereas the reverse reaction (electrolysis) cannot occur without some external help. Another example is that of adding milk to hot coffee. As soon as the milk is added to the coffee, the reverse action is impossible to achieve. These events are explained by the Second Law of Thermodynamics, which provides the necessary tools to rule out impossible processes by analyzing the events occurring around us with respect to time. Contrary to the First Law of Thermodynamics, the Second Law is sensitive to the direction of the process.

To understand the second law of thermodynamics better, we must introduce a thermodynamic property called entropy (symbolized by S, representing total entropy, and s, representing entropy per unit mass). The entropy of a system is simply a measure of the degree of molecular chaos or disorder at the microscopic level within a system.

The more disorganized a system is, the less energy is available to do useful work; [3] in other words, energy is required to create order in a system. When a system goes through a thermodynamic process, the natural state of affairs dictates that entropy be produced by that process. In essence, the Second Law of Thermodynamics states that, in an isolated system, entropy can be produced, but it can never be destroyed.

$$\Delta S = S_{final} - S_{initial} \geqslant 0 \tag{1-2}$$

Thermodynamic processes can be classified as reversible and irreversible processes. A reversible process is a process during which the net entropy of the system remains unchanged. A reversible process has equal chances of occurring in either a forward or backward direction because the net entropy remains unchanged. The absolute incremental entropy change for a closed system of fixed mass in a reversible process can be calculated from

$$dS = \frac{dQ}{T} \tag{1-3}$$

where dS is the increase in entropy, dQ is the heat absorbed, and T is the absolute temperature. We emphasize that most real processes are not reversible and the entropy of a real process is not usually conserved. Therefore, Eq. (1-3) can be written in a general form as

$$dS \geqslant \frac{dQ}{T} \tag{1-4}$$

where the equality represents the reversible process. A reversible process in which $dQ = 0$ is called an isentropic process. It is obvious from Eq. (1-4) that for such processes, $dS = 0$, which means that no net change occurs in the entropy of the system or its surroundings.

APPLICATION OF THE THERMODYNAMIC LAWS TO HVAC AND OTHER ENERGY CONVERSION SYSTEMS

We can now employ these thermodynamic laws to analyze thermodynamic processes that occur in energy conversion systems. Among the most common energy conversion systems are heat engines and heat pumps. In Fig. 1-3, the Solid lines indicate the operating principle of a heat engine, where energy

$$\eta_{\text{heat engine}} = \frac{\text{desired output energy}}{\text{required input energy}} = \frac{w}{Q_H} \tag{1-5}$$

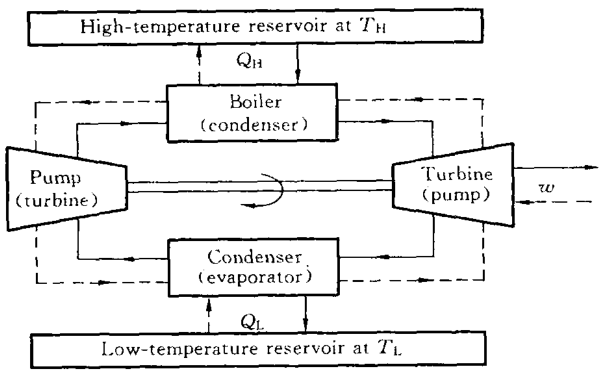

Fig. 1-3 Principle of operation of a heat engine (solid lines and upper terms) and heat pump (dashed lines and lower terms in parentheses)

In the early 1800s, Nicholas Carnot showed that to achieve the maximum possible efficiency, the heat engine must be completely reversible (i. e., no entropy production, no thermal losses due to friction).

Carnot's heat engine should give

$$\Delta S = \frac{Q_H}{T_H} - \frac{Q_L}{T_L} = 0 \tag{1-6}$$

Therefore, the maximum possible efficiency is

$$\eta_{\text{rev}} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{T_L}{T_H} \tag{1-7}$$

Terms and Expressions

thermodynamics 热力学

heat engine 热机

heat pump 热泵

entropy 熵

enthalpy 焓

condensor 冷凝器

evaporator 蒸发器

control volume(CV) 控制体积

refrigerant 制冷剂

saturated 饱和的

HVAC(Heating Ventilating Air Conditioning) 供暖通风空调

Notes

1. In this heat pump, a working fluid (R-22, a common refrigerant used with geothermal heat pumps, which is gaseous at room temperature and pressure) is sealed in a closed loop and

is used as the transport medium for energy.

在这个热泵系统中,工质被密封在一个闭式循环中并充当传输能量的介质。通常情况下,地源热泵系统常采用的 R22 作为工质,它在常温常压下是气态。

2. The cool working fluid exiting the condenser is a high-pressure liquid (point 4), which then passes through an expansion device or valve to reduce its pressure to that of the evaporator (underground loop).

离开冷凝器,经过冷却后的工质的状态为高压液体,通过膨胀装置或者是膨胀阀的减压进入蒸发器(地下换热循环)。

3. The more disorganized a system is, the less energy is available to do useful work.

系统越无序,可用于做有用功的能量越少。

Answer the Following Questions in English

1. What is an isolated system?
2. Can you cool off your apartment by leaving the door of the refrigerator open?
3. How do the first and second law of thermodynamics apply to hydroelectricity?
4. Which is more efficient, a steam engine operating between 100 ℃ and 200 ℃ or one operating between 100 ℃ and 400 ℃?

Translate the Following Paragraphs into English

1. 热力学第一定律是进行热力分析、建立能量平衡方程的理论依据,它奠定了能量在数量上分析计算的基础。针对不同的热力系、不同的情况,热力学第一定律可能有不同的形式,然其实质无非是热力系在完成传递和转换能量时收支平衡,即进入热力系的能量一离开热力系的能量=热力系储存能量的变化。

2. 热力学第二定律是应用极为广泛的基本定律,它不仅是热力学领域内重要的基本定律,而且可以用于许多自然想象的研究,人们运用熵的观点于哲学、经济学、社会学等问题的研究分析,获得了很大的成功。

3. 能量的转换与工质的状态有关,同时转换中能量还有质的差异,因此,要把转移的能量和存储于热力系的能量分开。

1.2 Heat Transfer

Thermodynamic laws are always concerned with the equilibrium state of a system and are used to determine the amount of energy required for a system to change from one equilibrium state to another. These laws do not quantify the mode of the energy transfer or its rate. Heat transfer relations, however, complement thermodynamic laws by providing rate equations that relate the heat transfer rate between a system and its environment.

Heat transfer is an important process that is an integral part of our environment and daily life. The heat-transfer or heat-exchange process between two media occurs as a result of a temperature difference between them. Heat can be transferred by three distinct modes: conduction, convection, and radiation. Each one of these heat transfer modes can be defined by an appropriate rate equation presented below: Fourier's Law of Heat Conduction

$$Q_{cond} = -kA\frac{dT}{dx} \tag{1-8}$$

Newton's Law of Cooling—which gives the rate of heat transfer between a surface and a fluid

$$Q_{conv} = -hA\Delta T \tag{1-9}$$

where h is the average heat-transfer coefficient over the surface with area A. Stefan - Boltzmann's Law of Radiation—which is expressed by the equation

$$Q_r = A_1 F_{1\text{-}2}\sigma(T_1^4 - T_2^4) \tag{1-10}$$

CONDUCTION HEAT TRANSFER

Conduction is the heat-transfer process that occurs in solids, liquids, and gases through molecular interaction as a result of a temperature gradient. The energy transfer between adjacent molecules occurs without significant physical displacement of the molecules. The rate of heat transfer by conduction can be predicted by using Fourier's law, where the effect of molecular interaction in the heat-transfer medium is expressed as a property of that medium and is called the thermal conductivity. The study of conduction heat transfer is a well-developed field where sophisticated analytical and numerical techniques are used to solve many problems in buildings including heating and cooling load calculation. [1]

In this section, we discuss basics of steady-state one-dimensional conduction heat transfer through homogeneous media in Cartesian and cylindrical coordinates. Some examples are provided to show the application of the fundamentals presented, and we also discuss fins or extended surfaces.

ONE-DIMENSIONAL STEADY-STATE HEAT CONDUCTION

Fourier's law states that the rate of heat transferred by conduction is directly proportional to the temperature gradient and the surface area through which the heat is flowing. The proportionality constant k is the thermal conductivity of the heat-transfer medium. Thermal conductivity is a thermophysical property and has units of W/m K in the SI system, or Btu/h ft °F in the English system of units. Thermal conductivity can vary with temperature, but for most materials it can be approximated as a constant over a limited temperature range.

THE CONCEPT OF THERMAL RESISTANCE

Fig. 1-4 also shows the analogy between electrical and thermal circuits. Consider an electric current I flowing through a resistance R_e, as shown in Fig. 1-4. The voltage difference $\Delta V = V_1 - V_2$ is the driving force for the flow of electricity. The electric current can then be calculated from

$$I = \frac{\Delta V}{R_e} \tag{1-11}$$

CONVECTION HEAT TRANSFER

Energy transport (heat transfer) in fluids usually occurs by the motion of fluid particles.

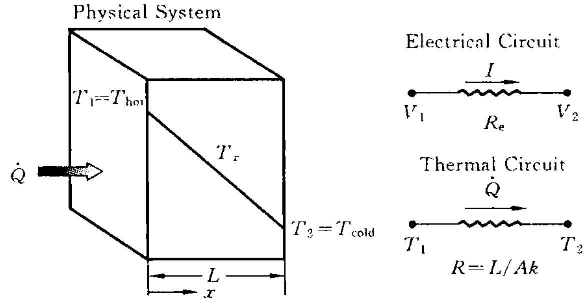

Fig. 1-4 Analogy between thermal and electrical circuits for steady-state conduction through a plane wall

In many engineering problems, fluids come into contact with solid surfaces that are at different temperatures from the fluid. The temperature difference and random/bulk motion of the fluid particles result in an energy transport process known as convection heat transfer. Convection heat transfer is more complicated than conduction because the motion of the fluid, as well as the process of energy transport, must be studied simultaneously. Convection heat transfer can be created by external forces such as pumps and fans in a process referred to as forced convection. In the absence of external forces, the convection process may result from temperature or density gradients inside the fluid; in this case, the convection heat-transfer process is referred to as natural convection. There are other instances where a heat-transfer process consists of both forced and natural convection modes and they are simply called mixed-convection processes.

The main unknown in the convection heat-transfer process is the heat-transfer coefficient. Fig. 1-5 serves to explain the convection heat-transfer process by showing the temperature and velocity profiles for a fluid at temperature T_∞ and bulk velocity U_∞ flowing over a heated surface. As a result of viscous forces interacting between the fluid and the solid surface, a region known as velocity boundary layer is developed in the fluid next to the solid surface. In this region the fluid velocity is zero at the surface and increases to the bulk fluid velocity U_∞. Because of the temperature difference between the fluid and the surface, a region known as temperature boundary layer also develops next to the surface, where the temperature at the fluid varies from T_w (surface temperature) to T_∞ (bulk fluid temperature). The velocity-boundary-layer thickness δ and temperature-boundary-layer thickness δ_t and their variation along the surface are shown in Fig. 1-5.

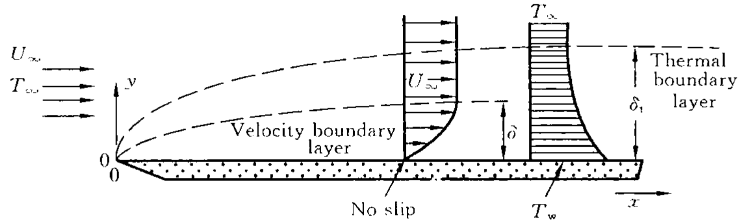

Fig. 1-5 Temperature and velocity profiles for convection heat-transfer process over a heated surface

Depending on the thermal diffusivity and kinematic viscosity of the fluid, the velocity and temperature boundary layers may be equal or may vary in size[2]. Because of the no-slip condition at the solid surface, the fluid next to the surface is stationary; therefore, the heat transfer at the interface occurs only by conduction.

If the temperature gradient were known at the interface, the heat exchange between the fluid and the solid surface could be calculated, where k in this case is the thermal conductivity of the fluid and dT/dx (or dT/dy in reference to Fig. 1-5) is the temperature gradient at the interface. However, the temperature gradient at the interface depends on the macroscopic and microscopic motion of fluid particles. In other words, the heat transferred from or to the surface depends on the nature of the flow field.

Therefore, in solving convection problems, engineers need to determine the relationship between the heat transfer through the solid-body boundaries and the temperature difference between the solid-body wall and the bulk fluid. Note that h depends on the surface geometry and the fluid velocity, as well as on the fluid's physical properties. Therefore, depending on the variation of the above quantities, the heat-transfer coefficient may change from one point to another on the surface of the solid body. As a result, the local heat-transfer coefficient may be different from the average heat-transfer coefficient. However, for most practical applications, engineers are mainly concerned with the average heat-transfer coefficient, and in this section we will use only average heat-transfer coefficients unless otherwise stated.

RADIATION HEAT TRANSFER

Thermal radiation is a heat-transfer process that occurs between any two objects that are at different temperatures. All objects emit thermal radiation by virtue of their temperature. Scientists believe that the thermal radiation energy emitted by a surface is propagated through the surrounding medium either by electromagnetic waves or is transported by photons. In a vacuum, radiation travels at the speed of light C_0 (3×10^8 m/s in a vacuum); however, the speed of propagation c in a medium is less than C_0 and is given in terms of index of refraction of the medium. The radiation wavelength depends on the source frequency and refractive index of the medium through which the radiation travels, according to the equation

$$c = \lambda v = \frac{C_0}{n} \tag{1-12}$$

where n = index of refraction of the medium;

$C_0 = 3\times10^8$ m/s (9.84×10^8 ft/s);

λ = wavelength, m (ft);

v = frequency, s^{-1}.

Thermal radiation can occur over a wide spectrum of wavelengths, namely between 0.1 and 100 μm. The spectral distribution and the magnitude of the emitted radiation from an object depends strongly on its absolute temperature and the nature of its surface. For example, at the surface temperature of the sun, 5 800 K, most energy is emitted at wavelengths near 0.3 μm. However, thermal processes within buildings occur at 10 μm. This particular radiation-process property has caused environmental concerns such as global warming (or the greenhouse effect) in recent years. Global warming is a result of the increased amount of carbon dioxide in the atmosphere. This gas absorbs radiation from the sun at shorter wavelengths but is opaque to emitted radiation from the earth at longer wavelengths, thereby trapping the thermal energy and causing a gradual warming of the atmosphere,[3] as in a greenhouse. A perfect radiator—called a blackbody—emits and absorbs the maximum amount of radiation at any wavelength.

RADIATION PROPERTIES OF OBJECTS

When radiation strikes the surface of an object, a portion of the total incident radiation is reflected, a portion is absorbed, and if the object is transparent, a portion is transmitted through the object as depicted in Fig. 1-6.

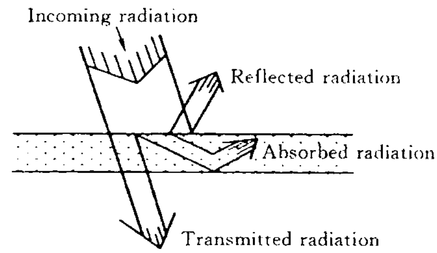

Fig. 1-6 Radiation strikes the surface of an object

The fraction of incident radiation which is reflected is called the reflectance (or reflectivity) ρ, the fraction transmitted is called the transmittance (or transmissivity) τ, and the fraction absorbed is called the absorptance (or absorptivity) α. There are two types of radiation reflections: specular and diffuse. A specular reflection is one in which the angle of incidence is equal to the angle of reflection, whereas a diffuse reflection is one in which the incident radiation is reflected uniformly in all directions. Highly polished surfaces such as mirrors approach the specular reflection characteristics, but most industrial surfaces (rough surfaces) have diffuse reflection characteristics. By applying an energy balance to the surface of the object the relationship between these properties can be expressed as

$$\alpha+\rho+\tau=1 \tag{1-13}$$

Terms and Expressions

Fourier's Law 傅立叶定律
evaporator 蒸发器
thermophysical 热物性的
kinematic viscosity 动力黏度
spectral 光谱的
heat-transfer coefficient 传热系数
refraction 折射
absorptivity 吸收率
Cartesian coordinates 笛卡尔坐标系
thermal conductivity 导热系数

Notes

1. The study of conduction heat transfer is a well-developed field where sophisticated analytical and numerical techniques are used to solve many problems in buildings including heating and cooling load calculation.

对于导热问题的研究已经十分成熟，较为成熟的分析解法以及数值方法已经能够解决很多建筑中的导热问题，包括冷热负荷的计算。

2. Depending on the thermal diffusivity and kinematic viscosity of the fluid, the velocity and temperature boundary layers may be equal or may vary in size.

速度边界层和温度边界层尺寸可能相同也可能不同，这取决于流体的热扩散率和运动黏度。

3. This gas absorbs radiation from the sun at shorter wavelengths but is opaque to emitted radiation from the earth at longer wavelengths, thereby trapping the thermal energy and causing a gradual warming of the atmosphere.

这种气体能吸收太阳短波辐射，但是地面的长波辐射却无法穿透它，因此它“捕获”了热能，导致大气温度逐步升高。

Answer the Following Questions in English

1. How is heat transferred between objects, fluids, and gases?
2. Which conducts heat better? Silver, Gold, Platinum, Copper, Aluminum?
3. How is natural convection different from forced convection?

Translate the Following Paragraphs into English

1. 物体各部分之间不发生相对位移时，依靠分子、原子以及自由电子等微观粒子的热运动而产生的热量传递称为导热。例如，物体内部热量从温度较高的部分传递到温度较低的部分，以及温度较高的物体把热量传递给与之接触的温度较低的另一物体都是导热现像。

2. 对流是指由于流体的宏观运动，从而流体各部分之间发生相对位移、冷热流体相互掺混所引起的热量传递过程。

3. 物体通过电磁波来传递能量的方式称为辐射。物体会因各种原因发出辐射能，其中因热的原因而发出辐射能的现象称为热辐射。

1.3 Fluid Mechanics

The distribution of heated and cooled fluids by pipes and ducts, is an essential part of many industrial processes and systems. The fluids encountered in these processes are gases, vapors, liquids, or mixtures of liquid and vapor (two phase flow). This section briefly reviews certain basic concepts of fluid mechanics that are often encountered in analyzing and designing HVAC systems. Fluid flowing through a conduit will encounter shearing forces that result from viscosity of the fluid. The fluid undergoes continuous deformation when subjected to these shearing forces. Furthermore, as a result of shearing forces, the fluid will experience pressure losses as it travels through the conduit.

Viscosity μ, is a property of fluid best defined by Newton's Law of Viscosity

$$\tau = \mu \frac{du}{dy} \tag{1-14}$$

where τ is the frictional shearing stress, and du/dy represents the measure of the motion of one layer of fluid relative to an adjacent layer. The following observation will help to explain the relationship between viscosity and shearing forces. Consider two very long parallel plates with a fluid between them, as shown in Fig. 1-7. Assume a uniform pressure throughout the fluid. The upper plate is moving with a constant velocity u_0, and the lower plate is stationary. Experiments show that the fluid adjacent to the moving plate will adhere to that plate and move along with the plate at a velocity equal to u_0, whereas the fluid adjacent to the stationary plate

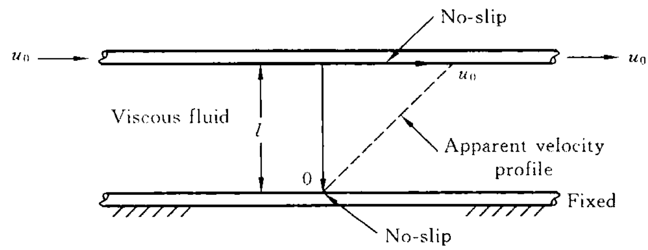

Fig. 1-7 A fluid sheared between two parallel plates

will have zero velocity. The experimentally verified velocity distribution in the fluid is linear and can be expressed as

$$u = \frac{y}{l} u_0 \tag{1-15}$$

Where l is the distance between the two parallel plates. The force is necessary to keep the upper plate moving at a constant velocity if u_0 should be large enough to overcome (or balance) the frictional forces in the fluid. Again, experimental observations indicate that this force is proportional to the ratio u_0/l. One can conclude that u_0/l is equal to the rate of change of velocity, du/dy. Therefore, the frictional force per unit area (shearing stress), τ, is proportional to du/dy, and the proportionality constant is μ, which is a property of the fluid known as viscosity. The quantity μ is a measure of the viscosity of the fluid and depends on the temperature and pressure of the fluid. Equation (1-14) is analogous to Fourier's Law of Heat Conduction given by. Fluids that do not obey Newton's Law of Viscosity are called non-Newtonian fluids. Fluids with zero viscosity are known as inviscid or ideal fluids. Molasses and tar are examples of highly viscous liquids; water and air on the other hand, have low viscosities. The viscosity of a gas increases with temperature, but the viscosity of a liquid decreases with temperature. Reid, Sherwood, and Prausnitz (1977) provide a thorough discussion on viscosity.

FLOW CHARACTERISTICS

The flow of a fluid may be characterized by one or a combination of the following descriptor pairs: laminar/turbulent, steady/unsteady, uniform/nonuniform, reversible/irreversible, rotational/irrotational. In this section, however, we will focus our attention only on laminar and turbulent flows.

In laminar flow, fluid particles move along smooth paths in layers, with one layer sliding smoothly over an adjacent layer without significant macroscopic mixing. Laminar flow is governed by Newton's Law of Viscosity. Turbulent flow is more prevalent than laminar flow in engineering processes. In turbulent flow, the fluid particles move in irregular paths, causing an exchange of momentum between various portions of the fluid; adjacent fluid layers mix and this mixing mechanism is called eddy motion. In this type of flow, the velocity at any given point under steady-state conditions fluctuates in all directions about some time-mean value. Turbulent flow causes greater shearing stresses throughout the fluid, producing more irreversibilities and losses.[1] An equation similar to Newton's Law of Viscosity may be written