普通高等教育“十三五”规划教材

过程装备与控制工程专业英语教程

李晓红　吕　进　王宗明　主编

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前言

为适应我国对外开放和经济全球化发展的需求，既需要培养学生具有良好英语基础并能够进行专业沟通和交流的能力，同时又满足服务过程工业、适应机械、石油、石化、化工等行业的需求，因此，本教材课文与阅读材料选用时包含了：过程介质流动与传质传热、过程装备力学与材料、过程设备设计与安装、过程机械及过程装备控制等过程工业的主要内容。课文与阅读材料共计18个单元、54篇，均选自原版英文教科书、科技报告、著作等。阅读材料与课文具有相关性或是课文的续篇，以进一步拓宽阅读范围。根据课文与阅读材料内容，配备相应的练习题、注释和词汇表。附录为词汇总表及常用数学符号和数学式等读法列表。

本书unit 1～7由西安石油大学吕进编写，unit 9～15及unit 17～18由西安石油大学李晓红编写，unit 8和unit 16由中国石油大学（华东）王宗明编写。附录由李晓红、吕进整理。在本书的编写过程中得到了中国石化出版社等单位的大力支持，在此谨致衷心的感谢。

本书可作为过程装备与控制工程专业本科教材使用，也可作为相关专业研究生及工程技术人员的参考读本。

由于作者水平有限，书中如有错误或不妥之处，敬请读者批评指正。

编　者

目 录

Unit 1 Text

Engineering Thermodynamics (Ⅰ)

Although various aspects of what is now known as thermodynamics have been of interest since antiquity, formal study began only in the early 19th century through consideration of the motive power of *heat*: the capacity of hot bodies to produce *work*. Today the scope is larger, dealing generally with *energy* and *entropy* and with relationships among the *properties* of matter. Moreover, in the past 25 years engineering thermodynamics has undergone a revolution, both in terms of the presentation of fundamentals and in the manner that it is applied. In particular, the second law of thermodynamics has emerged as an effective tool for engineering analysis and design.

Fundamentals

Classical thermodynamics is concerned primarily with the macrostructure of matter. It addresses the gross characteristics of large aggregations of molecules and not the behavior of individual molecules. The microstructure of matter is studied in kinetic theory and statistical mechanics (including quantum thermodynamics). In this unit, the classical approach to thermodynamics is featured.

Basic Concepts and Definitions

Thermodynamics is both a branch of physics and an engineering science. The scientist is normally interested in gaining a fundamental understanding of the physical and chemical behavior of fixed, quiescent quantities of matter and uses the principles of thermodynamics to relate the *properties* of matter. Engineers are generally interested in studying *systems* and how they interact with their *surroundings*. To facilitate this, engineers have extended the subject of thermodynamics to the study of systems through which matter flows.

System

In a thermodynamic analysis, the *system is* the subject of the investigation. Normally the system is a specified quantity of matter and/or a region that can be separated from everything else by a well-defined surface. The defining surface is known as the *control surface* or *system boundary*. The control surface may be movable or fixed. Everything external to the system is the *surroundings*. A system of fixed mass is referred to as a *control mass* or as a *closed system*. When there is flow of mass through the control surface, the system is called a *control volume*, or *open system*. An *isolated* system is a closed system that does not interact in any way with its surroundings.

State, Property

The condition of a system at any instant of time is called its *state*. The state at a given instant of time is described by the properties of the system. A *property is any* quantity whose numerical value depends on the state but not the history of the system. The value of a property is determined in principle by some type of physical operation or test.

Extensive properties depend on the size or extent of the system. Volume, mass, energy, and entropy are examples of extensive properties. An extensive property is additive in the sense that its value for the whole system equals the sum of the values for its parts. *Intensive* properties are independent of the size or extent of the system. Pressure and temperature are examples of intensive properties.

A *mole is* a quantity of substance having a mass numerically equal to its molecular weight. Designating the molecular weight by M and the number of moles by n, the mass m of the substance is $m = n / M$. One kilogram mole, designated kmol, of oxygen is 32.0 kg. When an extensive property is reported on a unit mass or a unit mole basis, it is called a *specific* property. An overbar is used to distinguish an extensive property written on a per-mole basis from its value expressed per unit mass.

Process, Cycle

Two states are identical if, and only if, the properties of the two states are identical. When any property of a system changes in value there is a change in state, and the system is said to undergo a *process*. When a system in a given initial state goes through a sequence of processes and finally returns to its initial state, it is said to have undergone a *cycle*.

Phase and Pure Substance

The term *phase* refers to a quantity of matter that is homogeneous throughout in both chemical composition and physical structure. Homogeneity in physical structure means that the matter is all *solid*, or all *liquid*, or all *vapor* (or equivalently all *gas*). A system can contain one or more phases. For example, a system of liquid water and water vapor (steam) contains *two* phases. A *pure substance* is one that is uniform and invariable in chemical composition. A pure substance can exist in more than one phase, but its chemical composition must be the same in each phase. For example, if liquid water and water vapor form a system with two phases, the system can be regarded as a pure substance because each phase has the same composition. The nature of phases that coexist in equilibrium is addressed by the *phase rule*.

Equilibrium

Equilibrium means a condition of balance. In thermodynamics the concept includes not only a balance of forces, but also a balance of other influences. Each kind of influence refers to a particular aspect of thermodynamic (complete) equilibrium. *Thermal* equilibrium refers to an equality of temperature, *mechanical* equilibrium to an equality of pressure, and *phase* equilibrium to an equality of chemical potentials. *Chemical* equilibrium is also established in terms of chemical potentials. For complete equilibrium the several types of equilibrium must exist individually.

To determine if a system is in thermodynamic equilibrium, one may think of testing it as follows: isolate the system from its surroundings and watch for changes in its observable properties. If there are no changes, it may be concluded that the system was in equilibrium at the moment it was isolated. The system can be said to be at an *equilibrium state*. When a system is *isolated*, it cannot interact with its surroundings; however, its state can change as a consequence of spontaneous events occurring internally as its intensive properties, such as temperature and pressure, tend toward uniform values. When all such changes cease, the system is in equilibrium. At equilibrium temperature and pressure are uniform throughout. If gravity is significant, a pressure variation with height can exist, as in a vertical column of liquid.

Temperature

A scale of temperature independent of the *thermometric substance* is called a *thermodynamic* temperature scale. The Kelvin scale, a thermodynamic scale, can be elicited from the second law of thermodynamics.

To provide a standard for temperature measurement taking into account both theoretical and practical considerations, the International Temperature Scale of 1990 (ITS-90) is defined in such a way that the temperature measured on it conforms with the thermodynamic temperature, the unit of which is the Kelvin, to within the limits of accuracy of measurement obtainable in 1990.

Words and Expressions

1. thermodynamics [ˌθɜːmə(ʊ)daɪˈnæmɪks] *n.* 热力学
2. antiquity [ænˈtɪkwɪtɪ] *n.* 古物；古代遗物
3. motive power 动力，原动力；驱动工率
4. entropy [ˈentrəpɪ] *n.* 熵（热力学函数）
5. in terms of 依据；按照；在……方面；以……措词

6. fundamental [fʌndə'ment(ə)l] *n.* 基本原理;基本原则;*adj.* 基本的,根本的
7. macrostructure ['mækrə(ʊ)strʌktʃə] *n.* 宏观结构,宏观组织
8. address[ə'dres] *v.* 处理;讲话
9. aggregation [ˌægrɪ'geɪʃən] *n.* 聚合,聚集;聚集体,集合体
10. kinetic theory 动力论;分子运动论
11. mechanics [mɪ'kænɪks] *n.* 力学(用作单数);结构;技术;机械学(用作单数)
12. statistical mechanics 统计力学
13. quantum ['kwɒntəm] *n.* 量子论;额(特指定额、定量)
14. quiescent [kwɪ'es(ə)nt;kwaɪ-] *adj.* 静止的;不活动的;沉寂的
15. quantities of 大量的,许多的
16. facilitate [fə'sɪlɪteɪt] *v.* 促进;帮助;使容易
17. referred to as 被称为……
18. isolated system 孤立系统,隔离系统
19. at any instant 在任何时刻,在任何情况下
20. in principle 大体上,原则上,基本上,一般而言
21. in the sense 就……意义而言
22. intensive property 强度性质;内涵性质
23. extensive property 扩延性质;广度性质
24. specific property 种的特性,比性质
25. homogeneous [ˌhɒmə(ʊ)'dʒiːnɪəs;-'dʒen-] *adj.* 均匀的;同种的;同质的
26. elicit [ɪ'lɪsɪt] *v.* 抽出,引出;引起
27. a quantity of 一定量的,一些,许多
28. initial state 初态;起始状态,开始状态
29. equilibrium [ˌiːkwɪ'lɪbrɪəm;ˌekwɪ-] *n.* 均衡;平衡
30. chemical potential 化学势,化学位
31. watch for 等待;当心;守候
32. spontaneous [spɒnˌteɪnɪəs] *adj.* 自发的;自然的
33. internally [in'təːnəli] *adv.* 内部地;国内地;内在地
34. throughout[θruː'aʊt] *adv.* 自始至终,到处;全部;*n.* 吞吐率,产量
35. Kelvin scale [热] 开氏,温标绝对温标;开尔文标度
36. thermometric [ˌθəːməu'metrik] *adj.* 寒暑表的;温度计的,测温的

Notes

1) An extensive property is additive in the sense that its value for the whole system equals the sum of the values for its parts. 意为:一个广义属性某种意义上是叠加的,即整个系统该属性的值等于这个系统各部分该值的加和。in the sense 是"某种意义"的意思。

2) A pure substance can exist in more than one phase, but its chemical composition must be the same in each phase. 意为：一个纯物质可以在多于一相中存在，但是该物质的化学组成在每一相中必须是一样的。phase 本句中指“相”。

3) A scale of temperature independent of the *thermometric substance* is called a *thermodynamic* temperature scale. The Kelvin scale, a thermodynamic scale, can be elicited from the second law of thermodynamics. 意为：独立于测温物质的温度尺度叫做热力学温标。开尔文温标，即热力学温标可以从热力学第二定律得出。elicite from 是“得出，引出”意思。

Exercises

1. Please pair off the following special terms with same meaning.

chemical potential
homogeneous
intensive property
isolated system
entropy
extensive property
thermale quilibrium
take into account
macrostructure
quantum thermodynamics
surroundings
control surface
state

强度性质
控制体表面
熵
环
化学势
孤立系统
热平衡
状态
量子热力学
考虑
广度性质
均匀的
宏观结构

2. Answer the following questions according to the text.

1) What is the definition of intensive property? Please give one or two examples.

2) What is the difference between an open system and an isolated system?

3) What is the definition of process?

3. Translate the following sentences into Chinese.

1) The scientist is normally interested in gaining a fundamental understanding of the physical and chemical behavior of fixed, quiescent quantities of matter and uses the principles of thermodynamics to relate the *properties* of matter.

2) When there is flow of mass through the control surface, the system is called a *control volume*, or *open system*.

3) *Thermal* equilibrium refers to an equality of temperature, *mechanical* equilibrium to an equality of pressure, and *phase* equilibrium to an equality of chemical potentials.

4) When a system in a given initial state goes through a sequence of processes and

finally returns to its initial state, it is said to have undergone a *cycle*.

4. Translate the following sentences orparagraphs into English.

1)经典热力学主要涉及物质的宏观结构。

2)当有质量流过控制表面时,系统称为控制体或开放系统。

3)一个系统在任何时刻的条件称为它的状态。

4)广度属性取决于系统的大小或范围。

Reading A

Engineering Thermodynamics (Ⅱ)

The First Law of Thermodynamics, Energy

Energy is a fundamental concept of thermodynamics and one of the most significant aspects of engineering analysis. Energy can be *stored* within systems in various macroscopic forms: kinetic energy, gravitational potential energy, and internal energy. Energy can also be *transformed* from one form to another and *transferred* between systems. For closed systems, energy can be transferred by *work* and *heat transfer*. The total amount of energy is *conserved* in all transformations and transfers.

Work

In thermodynamics, the term *work* denotes a means for transferring energy. Work is an effect of one system on another that is identified and measured as follows: work is done by a system on its surroundings if the *sole effect* on everything external to the system *could have been* the raising of a weight. The test of whether a work interaction has taken place is not that the elevation of a weight is actually changed, nor that a force actually acted through a distance, but that the sole effect *could be* the change in elevation of a mass. The magnitude of the work is measured by the number of standard weights that could have been raised. Since the raising of a weight is in effect a force acting through a distance, the work concept of mechanics is preserved. This definition includes work effects such as is associated with rotating shafts, displacement of the boundary, and the flow of electricity.

Work done *by* a system is considered positive: $W > 0$.

Work done *on* a system is considered negative: $W < 0$.

Energy

A closed system undergoing a process that involves only work interactions with its surroundings experiences an *adiabatic* process. On the basis of experimental evidence, it can be postulated that *when a closed system is altered adiabatically, the amount of work is fixed by the end states of the system and is independent of the details of the process.* This postulate, which is one way the *first law of thermodynamics* can be stated, can be made regardless of the type of work interaction involved, the type of process, or the nature of the system.

As the work in an adiabatic process of a closed system is fixed by the end states, an extensive property called *energy* can be defined for the system such that its change between two states is the work in an adiabatic process that has these as the end states. In engineering thermodynamics the change in the energy of a system is considered to be made up of three macroscopic contributions: the change in *kinetic energy*, KE, associated with the motion of the system *as a whole* relative to an external coordinate frame, the change in gravitational *potential energy*, PE, associated with the position of the system *as a whole* in the Earth's gravitational field, and the change in *internal energy*, U, which accounts for all other energy associated with the system. Like kinetic energy and gravitational potential energy, internal energy is an extensive property.

In summary, the change in energy between two states of a closed system in terms of the work W_{ad} of an adiabatic process between these states is

$$(KE_2-KE_1)+(PE_2-PE_1)+(U_2-U_1)=-W_{ad} \tag{1-1}$$

where 1 and 2 denote the initial and final states, respectively, and the minus sign before the work term is in accordance with the previously stated sign convention for work. Since any arbitrary value can be assigned to the energy of a system at a given state 1, no particular significance can be attached to the value of the energy at state 1 or at *any* other state. Only *changes* in the energy of a system have significance.

The specific energy (energy per unit mass) is the sum of the specific internal energy, u, the specific kinetic energy, $v^2/2$, and the specific gravitational potential energy, gz, such that

$$\text{specific energy}=u+\frac{v^2}{2}+gz \tag{1-2}$$

where the velocity v and the elevation z are each relative to specified datums (often the Earth's surface) and g is the acceleration of gravity.

A property related to internal energy u, pressure p, and specific volume v is *enthalpy* h, defined by

$$h=u+pv \tag{1-3}$$

or on an extensive basis

$$H=U+pV \tag{1-4}$$

Heat

Closed systems can also interact with their surroundings in a way that cannot be categorized as work, as, for example, a gas (or liquid) contained in a closed vessel undergoing a process while in contact with a flame. This type of interaction is called a *heat interaction*, and the process is referred to as *nonadiabatic*.

A fundamental aspect of the energy concept is that energy is conserved. Thus, since a closed system experiences precisely the same energy change during a nonadiabatic process as during an adiabatic process between the same end states, it can be concluded that the *net* energy transfer to the system in each of these processes must be the same. It follows that heat interactions also involve energy transfer. Denoting the amount of energy transferred *to* a closed system in heat interactions by Q, these considerations can be summarized by the *closed system energy balance*

$$(KE_2-KE_1)+(PE_2-PE_1)+(U_2-U_1)=Q-W \tag{1-5}$$

The closed system energy balance expresses the conservation of energy principle for closed systems of all kinds. The quantity denoted by Q in Equation (1-5) accounts for the amount of energy transferred to a closed system during a process by means other than work. On the basis of experiments it is known that such an energy transfer is induced only as a result of a temperature difference between the system and its surroundings and occurs only in the direction of decreasing temperature. This means of energy transfer is called an *energy transfer by heat*. The following sign convention applies:

$Q>0$ heat transfer to the system;

$Q<0$ heat transfer from the system.

Methods based on experiment are available for evaluating energy transfer by heat. These methods recognize two basic transfer mechanisms: *conduction* and *thermal radiation*. In addition, theoretical and empirical relationships are available for evaluating energy transfer involving *combined* modes such as *convection*.

The quantities symbolized by W and Q account for *transfers* of energy. The terms *work* and *heat* denote different *means* whereby energy is transferred and not *what* is transferred. Work and heat are not properties, and it is improper to speak of work or heat "contained" in a system. However, to achieve economy of expression in subsequent discussions, W and Q are often referred to simply as work and heat transfer, respectively. This less formal approach is commonly used in engineering practice.

Power Cycles

Since energy is a property, over each cycle there is no net change in energy. Thus, Equation 1-5 reads for *any* cycle

$$Q_{\text{cycle}}=W_{\text{cycle}} \tag{1-6}$$

That is, for *any* cycle the net amount of energy received through heat interactions is equal to the net energy transferred out in work interactions. A *power cycle*, or *heat* engine, is one for which a net amount of energy is transferred out by work: $W_{cycle} > 0$. This equals the net amount of energy transferred in by heat.

Power cycles are characterized both by addition of energy by heat transfer, Q_A, and inevitable rejections of energy by heat transfer, Q_R:

$$Q_{cycle} = Q_A - W_R \tag{1-7}$$

Combining the last two equations,

$$W_{cycle} = Q_A - Q_R \tag{1-8}$$

The *thermal efficiency* of a heat engine is defined as the ratio of the net work developed to the total energy added by heat transfer:

$$\eta = \frac{W_{cycle}}{Q_A} = 1 - \frac{Q_R}{Q_A} \tag{1-9}$$

The thermal efficiency is strictly less than 100%. That is, some portion of the energy Q_A supplied is invariably rejected $Q_R \neq 0$.

Words and Expreesions

1. conserve [kən'sɜːv] *v.* 保存;使守恒
2. external to 在……之外的;不相关的
3. in effect 实际上;生效,有效
4. adiabatic [ˌeɪdaɪə'bætɪk; ˌædɪə-] *adj.* 绝热的;隔热的;等焓的
5. postulate ['pɒstjʊleɪt] *n.* 基本条件;假定;*v.* 假定;要求;视……为理所当然
6. datum ['deɪtəm] *n.* 论据;基准;已知数;资料
7. idealization [ai'diəlai'zeiʃən, -li'z-] *n.* 理想化;理想化的事物
8. improper [ɪm'prɒpə] *adj.* 不正确的,错误的;不适当的

Reading B

Engineering Thermodynamics(Ⅲ)

The Second Law of Thermodynamics, Entropy

Many statements of the second law of thermodynamics have been proposed. Each of these can be called a statement of the second law *or* a corollary of the second law since, if one is invalid, all are invalid.

In every instance where a consequence of the second law has been tested directly or indirectly by experiment it has been verified. Accordingly, the basis of the second law, like every other physical law, is experimental evidence.

Kelvin-Planck Statement

The Kelvin-Planck statement of the second law of thermodynamics refers to a *thermal reservoir*. A *thermal reservoir is a system that remains at a constant temperature even though* energy is added or removed by heat transfer. A reservoir is an idealization, of course, but such a system can be approximated in a number of ways-by the Earth's atmosphere, large bodies of water (lakes, oceans), and so on. Extensive properties of thermal reservoirs, such as internal energy, can change in interactions with other systems even though the reservoir temperature remains constant, however.

The Kelvin-Planck statement of the second law can be given as follows: *it is impossible for any system to operate in a thermodynamic cycle and deliver a net amount of energy by work to its surroundings while receiving energy by heat transfer from a single thermal reservoir*. In other words, a *perpetual-motion machine of the second kind* is impossible. Expressed analytically, the Kelvin-Planck statement is

$$W_{cycle} \leqslant 0 (\textit{single reservoir}) \tag{1-10}$$

where the words *single reservoir* emphasize that the system communicates thermally only with a single reservoir as it executes the cycle. The "less than" sign applies when *internal irreversibilities* are present as the system of interest undergoes a cycle and the "equal to" sign applies only when no irreversibilities are present.

Irreversibilities

A process is said to be *reversible* if it is possible for its effects to be eradicated in the sense that there is some way by which *both* the system and its surroundings can be *exactly restored* to their respective initial states. A process is *irreversible* if there is no way to undo it. That is, there is no means by which the system and its surroundings can be exactly restored to their respective initial states.

Carnot Corollaries

The two corollaries of the second law known as *Carnot* corollaries state: (1) the thermal efficiency of an irreversible power cycle is always less than the thermal efficiency of a reversible power cycle when each operates between the same two thermal reservoirs; (2) all reversible power cycles operating between the same two thermal reservoirs have the same thermal efficiency. A cycle is considered *reversible* when there are no irreversibilities within the system as it undergoes the cycle, and heat transfers between the system and reservoirs occur ideally (that is, with a vanishingly small temperature difference).

Kelvin Temperature Scale

Carnot corollary 2 suggests that the thermal efficiency of a reversible power cycle operating between two thermal reservoirs depends only on the temperatures of the reservoirs and not on the nature of the substance making up the system executing the cycle or the series of processes. With Equation (1-9) it can be concluded that the ratio of the heat transfers is also related only to the temperatures, and is independent of the substance and processes:

$$\left(\frac{Q_C}{Q_H}\right)_{\text{revcycle}} = \psi(T_C, T_H) \tag{1-11}$$

where Q_H *is* the energy transferred to the system by heat transfer from a *hot* reservoir at temperature T_H, and Q_C is the energy rejected from the system to a *cold* reservoir at temperature T_C. The words *recycle* emphasize that this expression applies only to systems undergoing reversible cycles while operating between the two reservoirs. Alternative temperature scales correspond to alternative specifications for the function y in this relation.

The *Kelvin temperature scale is* based on $\Psi(T_C, T_H) = T_C/T_H$. Then

$$\left(\frac{Q_C}{Q_H}\right)_{\text{revcycle}} = \frac{T_C}{T_H} \tag{1-12}$$

Carnot Efficiency

For the special case of a reversible power cycle operating between thermal reservoirsat temperatures T_H and T_C on the Kelvin scale, combination of Equations 1-9 and 1-11 results in

$$\eta_{\max} = 1 - \frac{T_C}{T_H} \tag{1-13}$$

called the *Carnot efficiency*. This is the efficiency of *all* reversible power cycles operating between thermal reservoirs at T_H and T_C. Moreover, it is the *maximum theoretical* efficiency that any power cycle, real or ideal, could have while operating between the same two reservoirs. As temperatures on the Rankine scale differ from Kelvin temperatures only by the factor 1. 8, the above equation may be applied with either scale of temperature.

The Clausius Inequality

The Clausius inequality provides the basis for introducing two ideas instrumental for quantitative evaluations of processes of systems from a second law perspective: *entropy* and *entropy generation*. The Clausius inequality states that

$$\oint \left(\frac{\delta Q}{T}\right)_b \leqslant 0 \tag{1-14a}$$

The Clausius inequality can be expressed alternatively as

$$\oint \left(\frac{\delta Q}{T}\right)_b = -S_{gen} \tag{1-14b}$$