ROLE OF INFORMATION TECHNOLOGY IN ENHANCING ENGINEERING THERMODYNAMICS EDUCATION

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Abstract – *Thermodynamics is a subject that is important to engineers from a broad range of disciplines, including mechanical, electrical, chemical and materials engineers. Education methods over the last several years, have focused mainly on the presentation of the fundamental laws of thermodynamics as theorems based on experimental observations. More rigorous approaches have relied on the more general and physical principle of the law of stable equilibrium, from which the first and second laws of thermodynamics can be derived mathematically. While having the advantage of mathematical rigor, this latter approach is still somewhat abstract and does not illustrate the fundamental physical principles very well. In addition, it is necessary that the fundamental principles be taught in a way that it facilitates application to all engineering disciplines.*

The advances in microprocessor speed, and new software developments, can be utilized to illustrate the fundamental laws of thermodynamics to engineers. A few studies have been done in using computer models to illustrate the application of the first law, especially to cycle analysis such as Otto, Diesel and Brayton cycles. Energy and exergy optimizations and studies of new and modified cycles are becoming more common and are being introduced into the classrooms. Examples of these will be discussed in the presentation. However, there is still a need to employ physical models based on the properties of the individual molecules, employing the techniques of statistical thermodynamics, to illustrate in a clear manner, the basis for the fundamental thermodynamics laws. Advances in information technology can be a major source of help in this regard.

Index Terms – education, information technology, thermodynamics laws.

INTRODUCTION

The subject of thermodynamics has been developed over many years by numerous contributors spanning a variety of disciplines. Engineers, physicists, chemists, material scientists and others have postulated concepts, furnished theorems and provided physical data to establish the discipline. Early ideas dealing with heat (caloric) and power have lead to newer concepts such as entropy and exergy. Many of these concepts are based on experiments which are however not apparent in the teaching of thermodynamics to engineers.

Thermodynamics is a valuable and practical tool for a wide group of engineers including, electrical, mechanical, civil, chemical and materials engineers. The practical utility of thermodynamics lies in large measure, in the application of the fundamental laws of thermodynamics. Thus the proper understanding of the first and second laws of thermodynamics, the obtaining of property values for different substances, the state equations, the concept of equilibrium, power and refrigeration cycles, phase changes, solutions and two phase phenomena, etc. are all necessary components of an adequate education in engineering thermodynamics. This material must therefore be presented in such a way, especially in the first and second level thermodynamics courses, that engineers of all disciplines can understand the fundamental concepts and apply them to their respective trades. This presents special challenges.

THE FUNDAMENTAL LAWS OF THERMODYNAMICS

In teaching thermodynamics to engineers, the basic groundwork is established via the first and second laws of thermodynamics. These laws can be presented in three different ways to the students. The most commonly used approach is termed the Keenan [1] version of the laws, which are summarized as follows.

Keenan Statements of First and Second Laws (from [2])

First law. When any closed system is carried through a cycle, the summation (that is net) work delivered to the surroundings is proportional to the summation (that is net) heat taken from the surroundings. That is

$$\sum dQ = -\sum dW$$

Second law. It is impossible to construct a cyclically operating engine producing work that has no effect other than to raise a weight and abstract heat from a single reservoir.

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A second and somewhat less straight forward, formulation of the first and second laws is the Born-Caratheodory formulation also adopted by Kestin [3].

Born-Caratheodory Statement of the First and Second Laws

First Law

1. Given two arbitrary states of equilibrium 1 and 2 of any closed system, it is either possible to reach state 2 from state 1 or state 1 from state 2, but not both, by an adiabatic process involving the perfomance of work only.

2. The work performed is independent of the details of the process. This leads to

$$W_{ad} = U_2 - U_1$$

3. When a system changes from state 1 to state 2 by a non-adiabatic process, it is found that

$$W \neq U_2 - U_1$$

The difference $(U_2 - U_1) - W \neq 0$, implying an interaction other than work, is called heat.

Second Law

Statement 1. In the neighborhood of any given state of any closed system there exist states that are inaccessible from it along reversible, adiabatic paths.

Statement 2. In the neighborhood of any given state of any closed system there exist states that are inaccessible from it along any adiabatic path, reversible or irreversible.

A third formulation of the first and second laws, advocated by Haywood [4] and others, derives the cyclic statements of Keenan using the more general law of stable equilibrium as its starting point. This is sometimes called the 'single axiom' approach and was introduced in a formal manner by Hatsopoulas and Keenan [5]

Single Axiom Formulation of First and Second Laws

Single axiom approach. The law of stable equilibrium (LSE) states that a system having specified allowed states and an upper bound in volume can reach from any given state one and only one stable state and leave no effect on its environment.

Alternative statement. The LSE states that, from an initial allowed state, a constrained system which is permitted to undergo only such processes as leave no net effect on the environment can reach only one stable state.

The above statements of the two thermodynamics laws have been taken from Mayhew (2) who discusses them, but is of the conclusion that for engineers in particular, the Keenan approach stated above is best, although the Born-Caratheodory formulation does have certain advantages. The enunciation of the basic principles of thermodynamics through definitions and statements of the fundamental laws, as in the Keenan approach, does have the advantage of being straight forward. Complemented with examples and problems, this approach has been used in engineering education for many decades and has served the profession well.

INFORMATION TECHNOLOGY IN ENGINEERING THERMODYNAMICS EDUCATION

It is of utmost importance that the fundamental physical principles and concepts that led to the formulation of the thermodynamics laws be clearly imparted to engineering students. At this time, it cannot be stated that this has been successfully implemented. While it is true that advances in software development and microprocessor speed has significantly improved the tools available to illustrate engineering applications of thermodynamics, notably in the analysis of engineering power and refrigeration cycles, the same cannot be said of the fundamental concepts and axioms which are mostly accepted as definitive truths. This need still exists and will be discussed below. A few examples of information technology to the application of engineering thermodynamics in cycle analysis will be illustrated first.

INFORMATION TECHNOLOGY APPLICATIONS TO THERMODYNAMIC CYCLE ANALYSIS

Computer software has been in development over the last 20 years whereby students can get a better grasp of the applications of thermodynamics. In one of the earlier articles by Hinton and Wakeford [6] a number of software applications of engineering thermodynamics is listed. A few relevant from a variety of sources are described below.

1. A computer based block design of Brayton cycle turbines with multiple compressors, intercoolers and regenerators has been used to illustrate the influence of components on cycle efficiency. Brayton cycle modeling continues even to the present time with increasing levels of component complexity and sophistication. (6, 7)

2. Computer software has been developed for illustrating of the compression, combustion and expansion processes of the four stroke spark ignition engine with and without heat transfer. [6]

3. The first law of thermodynamics has been applied to a combustion process to calculate final temperature and composition for various equivalence ratios, initial temperatures and pressures [6] for a few selected fuels.

4. Visualization of motion inside a sterling cycle cryocooler as a supplement to an experimental laboratory course [8] has been implemented via computer software. Engineering courseware on refrigeration cycle simulation has also been developed by Tan et al. [9] to permit better understanding of fundamental principles and optimize design.

5. A new computer aided instruction package, Cyclepad, has been utilized by Wu [10] at the U.S. naval Academy to educate students in the intelligent optimization of power and energy systems, and examples are discussed specifically relating to Brayton cycle performance.

6. An in-depth total design experience by students at the Imperial College, London using advanced software packages such as ProEngineer, ANSYS, STARCD and 'Concepts' turbomachinery design tools has been described by Court et al. [11]. The projects provided an excellent training experience to engineering students in applying thermodynamics principles to the design of a small 50 kW gas turbine engine. It spanned a period of 3 years and utilized experts from both academia and industry. Examples of such applications – oriented software will be illustrated in the presentation.

INFORMATION TECHNOLOGY AND ENGINEERING FUNDAMENTALS

Instructional tools using information technology are less frequently encountered which aid the student's understanding of the physical principles forming the basis for the postulates and definitions of thermodynamics. This is an important need because a firm grasp of these postulates and axioms are necessary for the proper understanding of thermodynamics. Currently, one feels more comfortable with the science of thermodynamics after a second course than with just the first course itself, and familiarity instills confidence. However, if information technology can be employed to clarify the fundamental principles and concepts, it will be possible to provide a firm grasp of the fundamentals of thermodynamics from the beginning. A few examples of existing tools and the need for additional ones are discussed.

1. Software to calculate the saturation curves and characteristic energy surfaces such as Gibbs energy as a function of pressure and temperature of a Van der Waals gas with constant specific heats at constant volume has been developed with the aid of Maxwell's equations (6). This provides insight into the obtaining of property values for single and two phase fluids.

2. A computer program for obtaining the thermodynamic properties of a non-ideal gas mixture has been utilized by Chaturvedi et al [11] for use in advanced undergraduate and beginning graduate level classes. Employing the Redlich-Kwong equation of state, they compute the compressibility factor, fugacity and partial molal properties of a mixture of nitrogen and oxygen. Students were exposed to a computer-aided methodology of solving practical problems while getting a better grasp of thermodynamic fundamentals.

USE OF STATISTICAL THERMODYNAMICS AND MICROPROCESSORS

An important tool or helping students understand the fundamental concepts and postulates of thermodynamics is the branch of statistical thermodynamics, because it is based on the physical properties of the molecules. Unfortunately, the mathematical sophistication required for a proper introduction of statistical thermodynamics is not easily available at the undergraduate level. However, this is an important area where information technology can make a contribution.

For example, the information technology view of the difficult concept of entropy can be illustrated by a microproessor simulation of a system of isolated distinguishable particles as they approach equilibrium from a specified distribution of energy levels. Random interaction of the particles exchanging energy according to appropriate transition probabilities can be permitted, and the corresponding population of the energy levels and entropy values can be monitored and plotted. The concept of equilibrium at maximum entropy level can be illustrated as the number of interactions increase for a given energy level. Thus the physical concepts can be utilized to illustrate complicated thermodynamic concepts by the aid of information technology. This methodology can be extended to illustrate the concept of reversibility in work interactions and heat interactions and can lead to a fundamental understanding of the first law of thermodynamics. The author is developing software utilizing these concepts, and they will be illustrated in the presentation.

SUMMARY

Over the last 20 years, advances in microprocessors and information technology has enhanced thermodynamics education especially in the area of power and refrigeration cycles and the calculation of property values of gases, gas mixtures and two phase systems. It is concluded that the need for using information technology to illustrate the fundamental concepts and postulates in the first and second level courses of thermodynamics still exists. One way this can be done is to combine the advances in microprocessor technology with the physical insights provided by statistical thermodynamics to elucidate, among other things, the first and second laws of thermodynamics to engineering students.

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