AC 2011-234: MAPPING THE FOREST OF DATA IN THERMODYNAMICS

Yumin Zhang, Southeast Missouri State University

Yumin Zhang Assistant Professor Department of Physics and Engineering Physics Southeast Missouri State University Phone: (573) 651-2391 E-mail: ymzhang@semo.edu Web: http://www.physics.semo.edu/

Mapping the Forest of Data

Abstract

There are two different methods of learning and teaching thermodynamics: the theoretical approach and the engineering approach. Unfortunately, neither of them is easy: The former involves intricate mathematical relationships and the latter employs a huge amount of data. In our department, the engineering approach is adopted, and thus the challenge for the students is to understand these data tables and apply them to solve problems. An effective way to help students grasp the underlying ideas is to use graphs and analogies. Yet another challenge for students is the concept of entropy. This issue can be addressed by revealing its multiple facets in different areas.

I. Introduction

Thermodynamics can be understood in different levels. First, it is a philosophy of the world, and almost all phenomena are governed by thermodynamics. Asides from its role in natural sciences, thermodynamics may also be applied to a variety of fields, such as economics[1, 2]. Second, it is a law for material structure. For example, phase transition or chemical reactions can be analyzed from the point of view of free energy[3, 4], which is a trade-off between energy and entropy. Third, it points out the direction of time[5], as all the irreversible processes will happen spontaneously only in one direction. Fourth, it is closely related to information[6], which shares the same formula with entropy.

Historically, thermodynamics was developed from the study of heat engines, and this is still the main topic in engineering thermodynamics. From one perspective, the function of heat engines is the transformation of internal energy to external energy. However, the internal energy is a complex function of state properties, thus it is more straightforward to express it in data tables, which is the most powerful tool for problem solving. On the other hand, this tool is not easy to grasp, as the classic textbook used in our class contains over eighty pages of data tables[7].

Most students are used to solving problems by means of equations, a method that is widely used in courses such as general physics and engineering mechanics. As a result, many students are at a loss when dealing with so much information and are unable to properly utilize it in their study. To assist students in this course, a new approach is needed. One way to do so is to reveal the macroscopic structure of the data, which can serve as a guide to this staggering wealth of information.

II. State and Property

Although the data of thermodynamic parameters cannot be modeled as simple analytical equations, they are actually well organized. The key concepts here are the *state* and its *properties*. This is analogous to a person and his/her possessions. In other words, the *properties* are organized around the *state*. In general, the state can be determined with two known properties. Afterwards, all other properties can be figured out from the state.

In order to convey this idea to the students, graphs and data plots are very helpful. At the beginning of this course, a *T*-*v* (temperature - specific volume) diagram is introduced and clearly shows the phase transition between compressed liquid and superheated vapor. Any point on this diagram corresponds to a *state*, which can be determined by the two properties *T* and *v*. However, this state is also related to a group of other properties, such as pressure (*P*), internal energy, enthalpy and entropy (s). As there are six properties commonly associated with a state, one can construct up to C_6^2 different diagrams. However, as *P* and *T* are two properties that can be measured easily, they are often considered as the primary properties. Just as in quantum mechanics, *P* and *T* are associated with two complementary properties *v* and *s*, and the product of each pair has the dimension of specific energy.

Thermodynamics problems often involve some processes, i.e., transitions of states. Typically one property is left unchanged, as in the cases of isochoric, isobaric, isothermal or isentropic process. Therefore, if the initial state is specified, the final state can be determined with an additional property. Using the first law of thermodynamics, heat exchange and work can be calculated. For example, as no work is done in an isochoric process, the amount of heat exchange can be figured out from the difference in internal energy. On the other hand, an adiabatic process allows work to be calculated from this difference in internal energy.

During the investigation of internal combustion engines, a *P*-*v* diagram is very helpful, as the work can be intuitively shown as the integral of pressure over volume. In addition, it is a simple matter to identify the processes corresponding to the four strokes of these engines. However, if the emphasis is on the heat exchange, a *T*-*s* diagram is more convenient. This is especially true for a Carnot cycle composed of isothermal and adiabatic processes, as the *T*-*s* diagram shows a rectangular plot and very easy to analyze.

III. Entropy

Perhaps the most challenging concept in thermodynamics is entropy, which may be defined from either macroscopic or microscopic perspectives. Engineering based textbooks often emphasize the macroscopic definition, i.e., its relationship with heat transfer. However, this approach has some limitations in that it is valid only for reversible processes. When students use the data tables to find the entropy, they are often puzzled by the fact that it depends on temperature as well as pressure or specific volume. On the other hand, the microscopic definition requires the background knowledge of statistical physics, which is not in the curriculum for engineering students. For a balanced approach, a simplified version of microscopic definition is introduced, thus allowing students to understand that the entropy is related to the occupied volumes in both real space and momentum space.

In order to help students understand entropy in depth, its applications in related areas are also introduced. One interesting topic is phase transition, which can be analyzed with the concept of Gibbs free energy: G = H – TS. This expression may be modeled as the competition between two rival forces: energy and entropy. For example, the condensation process lowers system energy, yet lowers entropy as well. Similarly, the evaporation process increases entropy, but energy also rises. Therefore, the outcome depends on the third parameter in the expression: temperature. When the temperature is high, entropy gets the upper hand and the system will be in a vapor phase. On the other hand, at lower temperature energy will win the competition and the system will exist in a liquid phase.

Yet another interesting topic is the relationship between entropy and information, which share the same formula. At absolute zero degree a uniform system will condense to the lowest energy state, causing the entropy to become zero. Similarly, at a perfectly symmetric and uniform configuration, the information is likewise zero. From this point of view, information is associated with symmetry breaking. For example, information in a computer's hard drive is recorded by the orientations of the tiny magnetic dipoles, while in the main memory (DRAM), the information is stored by capacitors with electric charges fulfilled or dumped. In addition, the DNA of living creatures uses four base pairs to record information, and it is more efficient than the binary systems used in computers. One can calculate the amount of information with a simple equation: $H = \log_2 W$, where W stands for the number of possible states. Following this formula, each magnetic dipole or each capacitor can only record 1 bit of information, while each base pair in DNA can record 2 bits of information.

Towards the end of the semester, students were required to write a term paper on the application of entropy in different areas. The students investigated many interesting topics, such as steam engines, chemical processes, biological systems, neural networks in brain, the birth and death of stars, black holes, global warming, economics and social organizations, etc. Through this term paper students expanded their perspective and realized that entropy is a very general concept which may be applied to many seemingly unrelated areas.

IV. Assessment

Two years ago the author taught this course for the first time, what he didn't realize was that the real challenge for the students was the difficulty in understanding the inner structure of these data tables. As a result, a few students failed to learn this course very well. The final exam scores of the whole class are shown in Fig. 1(a). In the fall of 2010, the author taught this course for a second time and issued a final exam which shared 90% of the problems used two years ago. Fig. 1(b) shows the scores of this final exam, and it indicates that the students' performance has improved significantly.

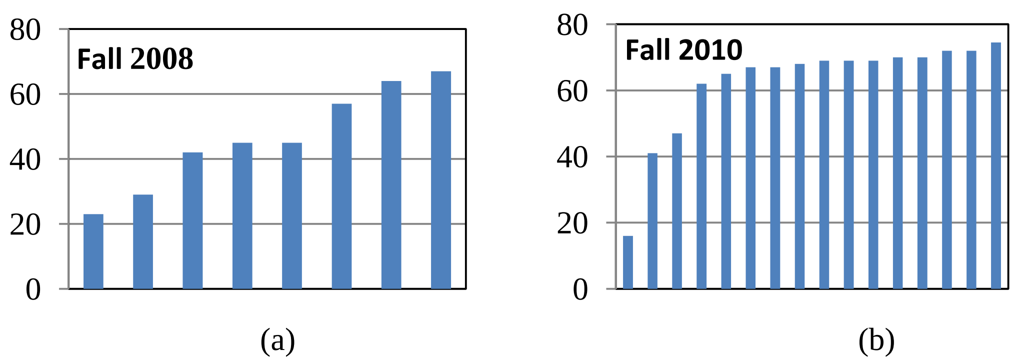

Fig. 1. Final exam scores with total of 75: (a) in fall 2008 and (b) in fall 2010.

From the students' course evaluation it is found that quite a few of them considered thermodynamics as pretty interesting rather than inconceivable. These assessment results demonstrate that the challenge of using data tables may be overcome by revealing their inner structure. In addition, most students realized that the laws in thermodynamics are powerful tools which can be applied to many different areas.

V. Conclusion

There are two major challenges in learning thermodynamics with an engineering approach: utilization of data tables and understanding entropy. With the emphasis on the relationship between *state* and these *properties*, these data tables can be well organized. The concept of entropy can be understood well with multiple approaches. Additionally, one can deepen the understanding by investigating its applications in different areas.

Acknowledgment

The author would like to acknowledge Skyler Marsh and Nathan Burford for reviewing this paper. Both of them are students who took this course in Fall 2010.

Reference

1. Nicholas Georgescu-Roegen, *The Entropy Law and the Economic Process*, iUniverse, 1999.
2. Robert Ayres, *Information, Entropy, and Progress: A New Evolutionary Paradigm*, Springer, 1997.
3. Vladimir Skripov, Mars Faizullin, *Crystal-Liquid-Gas Phase Transitions and Thermodynamic Similarity*, Wiley-VCH, 2006.
4. Irving Klotz, Robert Rosenberg, *Chemical Thermodynamics: Basic Concepts and Methods*, 7th ed. Wiley-Interscience, 2008.
5. Walter Grandy Jr., *Entropy and the Time Evolution of Macroscopic Systems*, Oxford University Press, 2008.
6. Thomas Cover, Joy Thomas, *Elements of Information Theory*, 2nd ed., Wiley-Interscience, 2006.
7. Claus Borgnakke, Richard E. Sonntag, *Fundamentals of Thermodynamics*, 7th ed., Wiley, 2008.