Teaching Thermodynamics without Tables – Isn't it Time?

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Abstract

The ability to use tables to determine properties of pure substances has been regarded as an essential component of knowledge of thermodynamics in both introductory and advanced courses. This ability was essential when there was no other reasonably convenient method to represent the complicated functional behavior of these properties. However, with the advent in the last decade of user-friendly computer programs such as *Engineering Equation Solver (EES)*[1], it is no longer necessary for students to master the skills of table look-ups in order to develop a good understanding of property behavior in thermodynamic applications. EES has thermophysical property functions built into a powerful equation solver program which allows students to consider a wider variety of problems and applications than would be feasible with table look-ups alone.

This paper discusses the pedagogical pros and cons of emphasizing the use of tables in introductory thermodynamics courses and the possibilities for minimizing or eliminating the tedium of using tables. The experience of the U.S. Coast Guard Academy in trying different approaches indicates that a "no tables" introductory course has the potential for increasing student understanding of basic principles and giving them a better appreciation for applications to practical engineering systems. Eliminating tables also helps combat the student perception that thermodynamics is an archaic science which is not amenable to the use of computer-based analytical tools.

I. Introduction

Most introductory thermodynamics textbooks[2-4] emphasize the use of tables to determine thermodynamic property values of both pure substances which can change phase and ideal gases with variable heat capacities. These tables have been essential when computational abilities have been limited, just as they were for trigonometric functions before the advent of scientific calculators and personal computers. As common computational tools have eliminated the use of tables for simpler functions, the use of thermodynamic tables is still common and frequently considered to be an essential component of knowledge of thermodynamics for students as well as practitioners. Questions requiring the use of thermodynamic tables are often included in the Fundamentals of Engineering (FE) Examination. Some textbooks now include computerized tables which facilitate the look-up process and minimize the need for interpolations. However, others now include access to equation solving software with built in thermodynamic property functions. This latter development significantly increases the range and variety of problems which can be investigated by students. The pedagogical possibilities opened up by the availability of this software opens the question of whether or not it is desirable or advantageous to incorporate property tables in introductory engineering thermodynamics courses.

II. Reasons for Using Tables

The use of tables to determine properties has been an essential component of the application of thermodynamics for close to one hundred years. For many engineering students, "learning thermodynamics" has been synonymous with developing a facility in using property tables. It may be difficult for faculty to imagine teaching thermodynamics without exposing students to the tools they had to master when they first encountered this science. However, this same situation existed thirty years ago in teaching trigonometry. Students had to develop a facility in using function tables in order to "do trigonometry." When scientific calculators came along, students were relieved of the tedium of tables. They may have lost some tools for understanding and visualizing the behavior of trig functions in the process, but now with graphical calculators, they have an even more powerful tool for gaining an understanding of this mathematical discipline. We may be facing a similar transition now with regard to thermodynamic property functions.

One argument for continuing to teach the use of tables is that they are currently more readily available than are computer software tools. If students or practitioners need to do an occasional thermodynamic analysis, they are more likely to find tables of properties than they are to have access to a suitable computer program. Essentially all thermodynamics textbooks and numerous engineering and scientific handbooks include property tables. These reference texts are also less expensive than are the software packages available commercially. If there were more demand for thermodynamic property computational tools, the developers of equation solver packages might be more inclined to include thermodynamic property functions along with other application packages. Just as computer based drawing and analytical tools are considered essential in many areas of engineering practice, those who expect to use thermodynamics might soon be expected to have access to analytical tools incorporating thermodynamic property functions.

It can certainly be argued that students who develop a facility with tables must have a basic understanding of the interrelationship of thermodynamic properties. However, it does not follow that students cannot develop a comparable level of understanding without using tables. Using property values to identify phase regions or processes that involve phase transitions are important skills which can be developed at least as effectively by requiring students to graph process lines using software capabilities as they can be by sifting through numbers in tables.

Some table "die-hards" may feel that thermodynamics is the last bastion where students may develop and exercise an ability to perform interpolation (both single and double). Since other disciplines like trigonometry have long since evolved beyond the use of tables, students do not come to thermodynamics with a facility in this skill. While some convoluted interpolation problems may exercise students' creativity in problem solving, it is difficult to argue that this arithmetical manipulation contributes to student understanding of thermodynamic principles and their application. On the contrary, students may be confused enough by the mechanics of the calculations that they lose sight of the important underlying principles.

A significant motivation for continuing to require students to learn to use property tables is that these tables may be used in the FE Exam. It would not be desirable to jeopardize students' chances to pass this exam and thus hinder their professional development. The primary reason that the use of tables might be included in the FE exam is that tables are currently so ubiquitous in the study of engineering thermodynamics. If software applications supplanted the use of tables, the FE exam would be expected to follow suit. Certainly tables applications are not required to test students understanding of thermodynamic principles, even if computers were not available to students taking the exam. Similarly, instructors who omit including the use of tables in introductory courses will have to be more creative in designing examinations in their courses.

III. Advantages of Using Computer Software Instead of Tables

Software packages like EES allow students to determine thermodynamic properties of most common substances straightforwardly and accurately without interpolation or manual iteration. Properties can be specified as a function of any two appropriate independent intensive properties. This allows for consideration of a wider range of problems and applications than can be treated simply with tables. For example, properties for a state which is determined by specifying the specific volume and internal energy can be determined easily using EES, while finding such a state using tables can require iteration and interpolation. Table 1 gives examples of some property functions which can be used in EES.

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P1= PRESSURE(Steam,T=T1,v=v1)
P2 = PRESSURE(Steam,u=u1,v=v1)
X1 = QUALITY(Steam,S=S2,P=P1)
TA = TEMPERATURE(R134a,h=h1,P=P1)
S1 = ENTROPY(Propane,T=TP,H=HP)
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Table 1. Sample EES Functions

To determine properties in the saturation region using tables, students must go through the intermediate step of determining the quality. This is not necessary with EES, although quality can be determined if knowledge of its value is useful or if the student desires to solve a problem with a constraint imposed on the quality. Problem solving is more straightforward when students can see that the conditions imposed by a problem allow them to specify two independent properties. Imposing intermediate steps can confuse this process.

Software such as EES allows students to produce quantitatively accurate graphs which increase their ability to visualize the variation of properties during processes. Figure 1 shows such a graph produced using EES which plots pressure as a function of specific volume for a constant temperature process for water going from saturated liquid to superheated vapor.

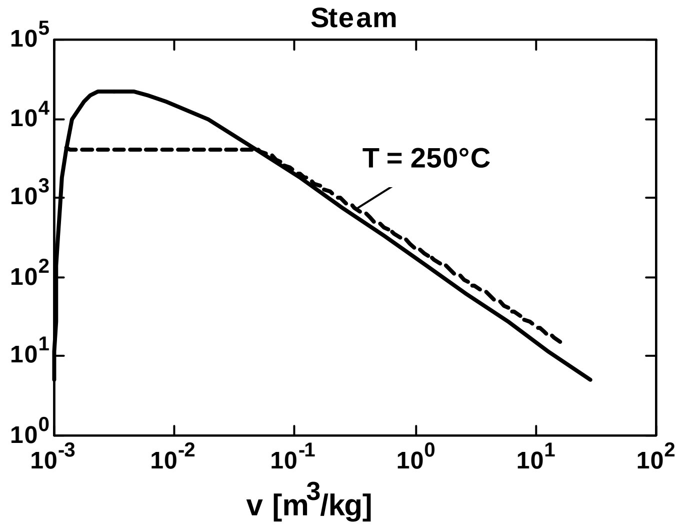

Figure 1. EES graph of P vs. v for a Constant Temperature Process

The analysis of thermodynamic systems is significantly facilitated with software such as EES. The ability to combine property functions with simultaneous equation solver capabilities allows the analysis of multiple component systems without the tedium of multiple table look-ups. This capability is particularly advantageous when system optimization problems are considered. A traditional problem which can be very tedious using tables is the optimization of the steam extraction pressure in a regenerative Rankine cycle. Optimization with tables would require analyzing a complete cycle multiple times to determine cycle efficiency for different extraction pressures. The approximate optimum could then be determined graphically. Using EES, such a graph can be produced straightforwardly with the student just setting up the system equations once and then using the optimization feature of EES or producing a table and graph of efficiency as a function of extraction pressure. Such a graph is shown in Figure 2.

Similar graphs of system characteristics such as efficiency as a function of any property in the system can be produced easily. Student understanding of system behavior can be significantly enhanced using this capability.

IV. Teaching Experience

At the U.S. Coast Guard Academy, we have tried introducing EES in the first thermodynamics course. In previous years, we had introduced this software in the second thermodynamics course, but students soon complained about not having this tool available to them when they began their study of thermodynamics. Students find the learning curve required to develop a facility with this program is not excessive, and the value of utilizing the program capabilities makes the learning effort well worthwhile. We have not yet completely eliminated the use of property tables, but students are looking forward to the day when the tables will be regarded as an anachronism.

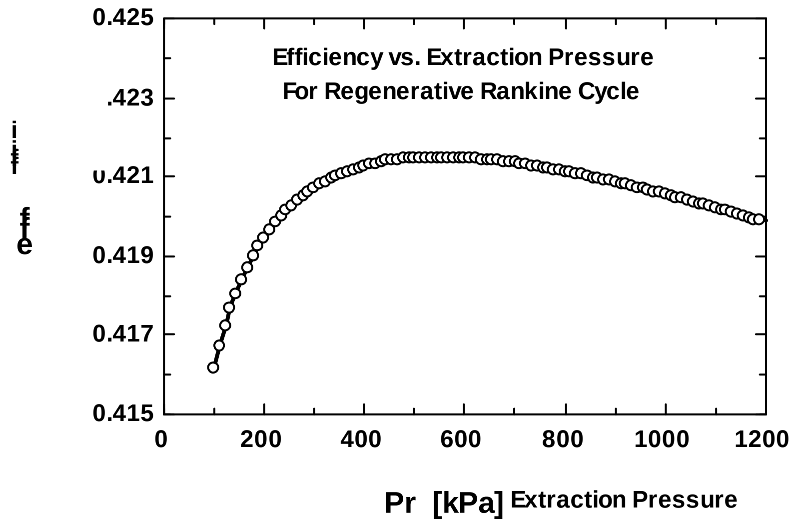

Figure 2. EES Graph of Efficiency vs. Extraction Pressure

V. Conclusions

With the advent of equation solving software incorporating thermodynamic property functions, tables are no longer necessary to obtain accurate property values. The effort required to learn how to use these tables and master the skills of interpolation may detract from the effort students put into learning to apply fundamental principles in the analysis of engineering systems. The flexibility and facility of use of software allows instructors to expose students to a wider variety of problems and applications than they can treat with tables alone. If some knowledge of tables is desirable, it is reasonable to expose students to tables after they have become familiar with the software. It may be time for engineers to relegate property tables to a footnote in the history of thermodynamics.

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