Are Steam Tables Running Out Of Steam?

Smitesh Bakrania
Rowan University

Abstract

Considering air and water are common power cycle working fluids, engineering thermodynamics courses begin with an introduction to the ideal gas law and the steam tables. The ideal gas law is a relatively straightforward concept. On the other hand, students often struggle with the steam tables. Instead, many students prefer to use computerized resources to determine steam properties. This paper highlights the deficiencies of both steam tables and popular computerized resources in their ability to reinforce the thermodynamics concepts. Thermodynamic properties are inter-related and therefore supplying state property values without emphasizing their relationships holds limited value from a student learning perspective. This paper recommends the use of property diagrams instead. Thermodynamic property diagrams are relatively simple to use, and more importantly, enable students to visualize the property relationships.

Keywords

Thermodynamics, Properties of Water, Steam Tables, Property Diagrams, Property Charts.

Introduction

Steam tables have been integral part of engineering thermodynamics since over a century. These tables of thermodynamic properties of water are used to study the ubiquitous Rankine power generation cycle. Almost all thermodynamics textbooks dedicate several pages of their appendices to the tabulated steam thermodynamic properties, conventionally separated by phases. The tables were originally developed to provide accurate steam property values to any trained engineer working in power generation industry. It is common practice for instructors to impart this traditionally valued skill to future engineers. The retrieval procedure begins with identifying the phase of water (namely, compressed liquid, saturated or superheated states) and may ultimately involve the need to interpolate to calculate the intermediate property values. Presently, the associated complexities and the easy access to numerous digital (computer or online) alternatives have made abandoning the traditional steam tables remarkably appealing. Several software-, online- and mobile-based tools exist to promptly deliver desired state properties.[1-7] Unlike steam tables, given two thermodynamic state properties, the rest of the properties can be quickly determined without the need to identify the phase or the need to interpolate. Here, we inherently recognize the inability of the digital database to reinforce fundamental thermodynamics concepts. However, this deficiency also exists with use of tabulated steam properties.

Both steam tables and the common digital resources supply state property values without reinforcing how the properties are related to each other. Emphasis is placed on the absolute property values rather than property relations. Without explicitly investigating the property trends, students using either tool fail to recognize how one property changes in response to the other. The knowledge of property relationships is more fundamental than the numeric value. In fact, it is common practice to sketch the states and processes on temperature versus entropy (*T-s)* diagrams to visualize the thermodynamics problems. Here, isentropic, isobaric, isothermal, etc., processes can be easily depicted to aid the analysis. Beyond simply visualizing the constant property processes, studying the relative changes in the subsequent state properties can provide meaningful insights into the processes themselves. Additionally, students may find it difficult to depict a constant specific volume v or constant density ρ process on a *T-s* diagram with the steam tables as the primary source for properties.

To emphasize property relations while eliminating the complexities associated with the use of steam tables, this paper advocates the use of detailed property diagrams to study thermodynamic processes. Property diagrams are powerful visual tools to retrieve property values. At the same time they afford deliberate emphasis on property relationships. If existing computational alternatives are integrated with property diagrams, there is evidence to suggest a positive impact on student learning as far as property trends are concerned.[8] The paper provides instructional guidelines to eliminate steam tables and emphasize property relations using property diagrams. The paper also discusses tools that can be used to harness the power of property visualization. Overall, steam tables have lost their relevance in modern engineering education. However there is a need to ensure the replacements to the steam tables reinforce the thermodynamics concepts while simplifying the process of retrieving property values.

Background

Thermodynamic Property Diagrams

Property diagrams of steam have likely existed as long as the steam tables have. They are simply the visual depiction of the property data. Property diagrams plot six the commonly used steam thermodynamic properties, namely, Pressure P, Temperature T, Specific Volume v, Specific Internal Energy u, Specific Enthalpy h, and Specific Entropy s on a two-dimensional graph. The most common of these is a *T-s* diagram that maps isobars and constant enthalpy lines. See Figure 1 for an example of the *T-s* diagram. Property diagrams are extremely useful to visualize phase change, and therefore *T-v* diagrams are regularly used to introduce the water properties. Students, quickly learn the constant property lines to visualize various processes they encounter - especially considering their previous exposure to the ideal gas processes on *P-v-T* space. However, due to the accuracy afforded by steam tables in practice, property diagrams are often relegated as a useful analytical aide when solving thermodynamic problems with steam.

On the Utility of Steam Tables

Once students are introduced to the overall property relations using property diagrams, they are taught how to retrieve the numeric property values from the steam tables. The steam tables are organized by phases (and the superheated region further separated by pressures) and only discrete values can be provided to limit total textbook pages dedicated to properties. The retrieval procedure can be complex and cumbersome. Besides their use during testing, students rely on online tools to confirm or to swiftly acquire their state values. Considering the additional time required teaching steam tables and for the students to develop comfort, when they can easily acquire values from online resources, what function do steam tables currently serve? The ability to use the steam table was critical when digital resources were not ubiquitous, as they are today. If the steam tables serve the function of delivering state property values, then the digital alternatives are more than adequate to rapidly and accurately supply property values.

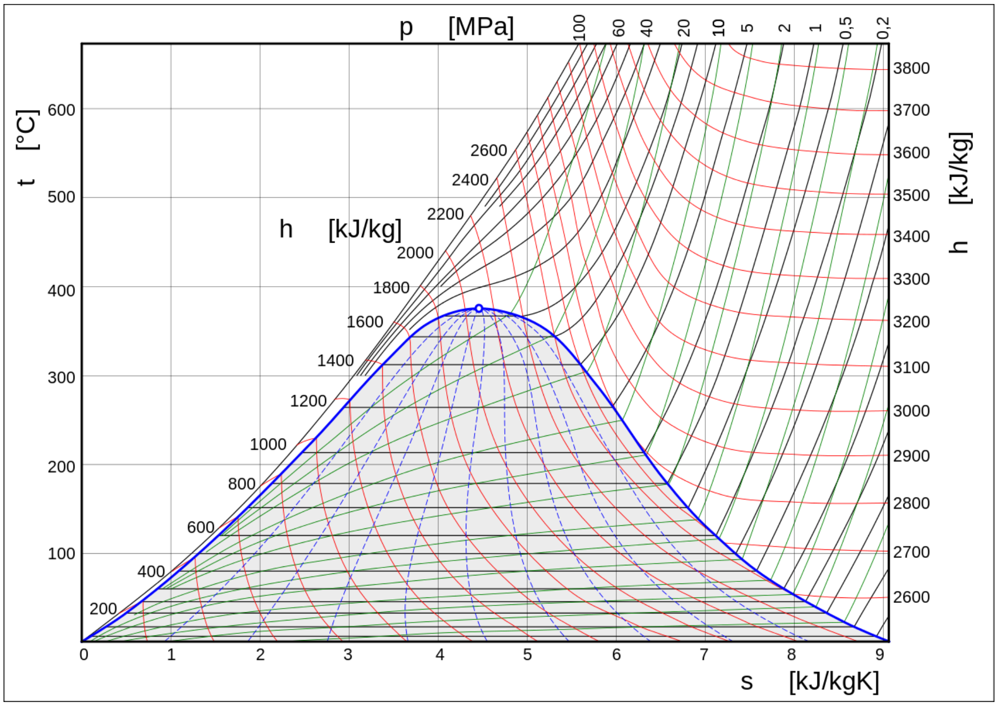

Figure 1. A Temperature-Entropy (*T-s*) diagram with red constant enthalpy *h* lines, green constant density *ρ* lines, and black constant pressure *P* lines (isobars). Note: the figure uses *t* instead of *T* for temperature. Created by *Kaboldy* for *Wikipedia.org.*

Replacing the Steam Tables

The use of steam tables has lost its relevance in modern engineering pedagogy and practice. With access to online information widely expanded by mobile devices, it is time to part with the steam tables. Rather than simply replacing steam tables with digital resources, it is valuable to extend the utility of thermodynamic property diagrams, with which the students are already familiar. A detailed thermodynamic property diagram that fits on a single printed page can supply the six commonly used thermodynamic properties with a reasonable precision to solve most of the fundamental engineering thermodynamics problems. Detailed *T-s* or *P-h* diagrams are readily available online and in several textbooks for offline usage. Students can print copies for use during problem solving and testing. Most importantly, with the use of property diagrams students visually reinforce their understanding of property relationships while retrieving property values. In essence, combining the visualization of thermodynamic processes and property value retrieval into a single intuitive step eliminates the need to master the arguably obsolete steam tables. Instead, teaching property diagrams requires significantly less time compared to the steam tables. Furthermore, the property retrieval procedure becomes a natural extension of the introduction to phase change in pure substances.

Among the several advantages of using property diagrams over steam tables, the key benefits can be summarized as:

- A full range of steam properties can be supplied on a single page
- Reduced instruction time devoted to teaching the steam tables
- Students become inherently aware of property trends and relationships
- Provide accurate visualization of thermodynamic processes and cycles
- Less emphasis on precision of property values and more on trends
- Phases are self-evident with known state values

However, the replacement of steam tables presents a challenge to the textbook-driven traditional instruction because textbooks continue to rely on steam tables. Therefore, an alternate method of instruction was developed and implemented in an existing course.

Instruction and Implementation

Phase change in pure substances is covered in the first few weeks of thermodynamics course. The topic is typically devoted a week of lectures that naturally transition from an advanced treatment of ideal gas laws where entropy *s* is briefly introduced as yet another thermodynamic property. Students may not understand entropy *s* as a concept but are made aware that it corresponds to the second law of thermodynamics. Steam properties are introduced using an atmospheric pressure example of water undergoing phase change (boiling at 100 ^{o}C) on a *T-v* diagram (see Figure 2(a)).

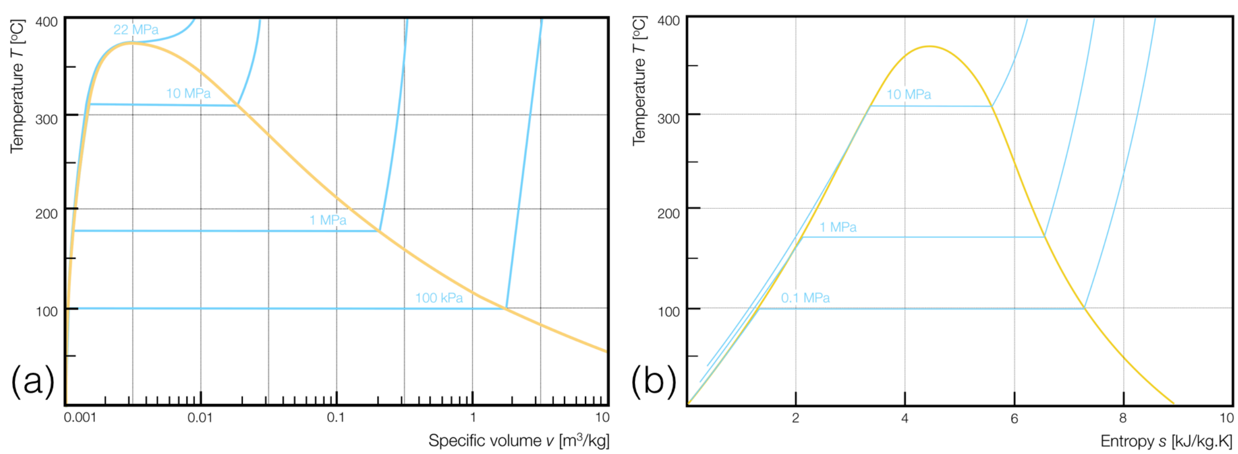

Figure 2. (a) *T-v* diagram depicting isobars used to demonstrate phase change of water from atmospheric conditions and (b) *T-s* diagram with the same isobars to highlight the similarities between the two diagrams and introduce entropy *s* as a 'yet another thermodynamic property'.

Upon describing the liquid-vapor mixture region, also known as vapor dome, the critical point and the superheated regions, in the past the students were taught how to obtain the various properties from the steam tables using the textbook appendices. Instead, this time students were shown a *T-s* diagram, which happens to map well to a *T-v* diagram. Using a diagram, such as the one presented in Fig. 2(b), similarities are identified and students are again reminded of entropy *s* as a property they will use at a later stage when discussing efficiencies of processes. For now, the students are asked to focus on the known thermodynamic properties of P and T.

Next, a detailed T-s diagram with isobars, constant density and constant enthalpy lines is presented from the Cengal, *et al.*, *Property Tables Booklet* (similar to the one presented in Fig. 1 but with density numeric values provided). Using the T-s diagram, the concept of mixture quality x is described. It is critical to reinforce that every point on the T-s diagram represents a thermodynamic state with defined thermodynamic property values ($P, T, h, \rho, s,$ and x). Considering the presentation of specific T-s diagram, students are reminded enthalpy represents the combination of internal energy u and flow work P/ρ (where $\rho = 1/v$). In other words, problems involving internal energy u will require subtracting the flow work term from enthalpy. This is a useful exercise to remind students how enthalpy h differs from internal energy u. Students need to be taught the process of reading constant density ρ lines that are separated logarithmically in this particular presentation of the T-s diagram.

Example problems involving steam properties are presented next. Example problems are used to help students practice property retrieval and emphasize property trends. For instance, the T-s diagram is used to highlight ideal gas behavior of steam to the far right of the vapor dome by observing that the constant enthalpy h lines are effectively a function of temperature (since superheated enthalpy lines are effectively horizontal on a T-s diagram, see Fig. 1). Using examples, students are shown how precision of steam property values minimally impact calculation of thermodynamic terms. For the Fall 2016 term, students were also asked to compare values obtained from the T-s diagram versus the steam table values. Students were asked to use the T-s diagram to complete the homework assignment and recognize that the numeric answers to the problems may not match the textbook solutions due to imprecise reading of the diagram, which was acceptable.

Supplementary Materials

Handouts consisting of a single page of a detailed T-s diagram were shared with the students to use during homework assignments and quizzes. For quizzes, students were only allowed to use the T-s diagram to solve steam-related problems. Additionally, to further familiarize students with the T-s diagram a T-shirt depicting the detailed diagram was designed for each student. Figure 3 provides a photograph of students with T-s diagram T-shirts. Students were also introduced to the Clausius mobile application; an app designed and developed by the author for the Apple iPad.[9] Clausius uses T-s, P-h and P-v diagram to supply thermodynamic properties as the users glide their fingers across the property diagram.[10] The app was also useful to demonstrate how properties evolve in real-time along a constant property line. Since Clausius serves as an analog to the printed property diagrams, students were encouraged to use the app for homework assignments but were limited to the printed version for quizzes. In a separate research study, the use of Clausius app has been shown to positively impact students' grasp of property trends in thermodynamics.[8]

Figure 3. Students and instructor from the Thermal-Fluid Science I section wearing custom-designed *T-s* diagram T-shirt.

Outcomes and Conclusion

Beyond the inherent benefits of eliminating the cumbersome steam tables, there were several advantages that were observed as a result of adopting property diagrams. Despite being instructor observations, as opposed to outcomes from a formal study, the following provide critical insights into the implementation.

- **Developing Comfort.** Majority of the students quickly mastered the property retrieval procedure, as opposed to the time required to master the use of steam tables.
- **Engaging with the Material.** Students often used multiple copies of the property diagram to solve individual problem so that they can mark and visualize the thermodynamic states directly on the *T-s* diagram.
- **Efficiency.** Students used less time to retrieve thermodynamic property values while solving problems when compared to the use of steam tables (especially if interpolation was involved).
- **Visual Aide.** Students were able to easily visualize constant density ρ, constant enthalpy h, and constant quality x processes directly on the *T-s* diagram. These processes are particularly difficult to visualize using steam tables.
- **Precision.** Initially, few students struggled with the imprecise nature of numeric solutions and checked their answers using the steam tables for accuracy. Once they were comfortable with this concept, the students used the *T-s* diagram exclusively.

Overall, the introduction of property diagrams as the primary source of water thermodynamic properties presented a notable advantage over the use of steam tables. Apart from practical benefits of the implementation, students became visually aware of property trends with the use of property diagrams. It is anticipated that the use of property diagrams will further facilitate the analysis of thermodynamic cycles involving phase change, namely, the Rankine Cycle and the Vapor-Compression Cycle. In conclusion, the exercise demonstrated property diagrams as superior replacements for traditional steam tables.

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Smitesh Bakrania

Dr. Smitesh Bakrania is an associate professor in Mechanical Engineering at Rowan University. He received his Ph.D. from University of Michigan in 2008 and his B.S. from Union College in 2003. His research interests include combustion synthesis of nanoparticles and combustion catalysis using nanoparticles. He teaches thermal-fluid sciences, combustion, and nanotechnology courses. He is also involved in developing educational apps for instructional and research purposes.