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From Data Graphs to AI: Considerations on Methods of Finding Thermodynamic Properties

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Abstract

Many engineering students have struggled while taking a thermodynamics course. Students often find the process of determining thermodynamic properties, particularly for substances either experiencing or near a phase transition (such as water/steam and refrigerants), to be confusing and difficult to learn. Struggles with finding thermodynamic properties will result in difficulties for the students when they are working to solve a first law or second law analysis problem, thereby hindering their mastery of those topics as well.

Historically, properties for substances like steam were found using graphs or tables of the property data. More recently, computer programs, Internet websites, and smartphone apps have become readily available to students and engineers for finding property data. This often makes finding the property data easier, but reliance on this method can be problematic when one is using a substance for which property calculation software has not been developed. Much more recently, the possibility of using AI tools such as ChatGPT has become available for finding property data. This has the potential of making finding property data on a larger number of substances easier.

Each of these techniques for finding thermodynamic properties have advantages and disadvantages, both from a pedagogical sense and a user viewpoint. In this paper, these techniques are summarized and the benefits and detriments of each will be explored. Additionally, the results of preliminary trials using AI tools to find thermodynamic property data are presented. Initial work with AI tools has revealed many problems that make the use of AI tools for finding thermodynamic properties unable to be recommended at this time.

Introduction

Engineering students in many disciplines need to take a basic course in engineering thermodynamics as part of their undergraduate studies. These courses are often taught from a mechanical engineering viewpoint. Despite the calculations performed in such a course being relatively simple compared to those in other engineering courses, students often struggle with their thermodynamics course. In some cases, this is due to it being a lower priority for them when compared to taking courses in their particular engineering major if the thermodynamics course is taught outside of the major (for example, a civil engineering student taking a thermodynamics course taught in mechanical engineering). In many cases, though, students struggle with trying to make the right decisions when solving problems in terms of piecing together their solution. Is the system open or closed? What quantities in the equations can be assumed to be zero? How do we find the properties for the substance being used? While making these decisions becomes easier with experience, it can be a struggle for many students when they are first taking the course. As a result, thermodynamics courses are sometimes dreaded by students before they start the course based on what they have heard from students who have previously taken the course. One step towards improving thermodynamics courses for students, and the students' learning of the material, is to consider how thermodynamics properties are found by the students.

Many introductory mechanical engineering thermodynamics courses divide substances into three categories for finding properties: solids and liquids (often treated as incompressible substances), gases (typically ideal), and substances undergoing a phase change or near a phase change (typically water or refrigerants). While there is usually some discussion of non-ideal behavior for substances in the first two of these categories, as the semester moves forward more consideration is generally paid to the ideal version of those substances so as to simplify the thermodynamic concepts being taught later in the course. Equations of state are developed for each of these types of substances, and methods of finding the thermodynamic properties are discussed. Unfortunately, it can become common for students to use the wrong methods for finding properties of a substance (for example, using relationships for an ideal gas to find properties of a saturated mixture of water) as they rush to finish a problem.

The primary focus of this paper is consideration of the different methods for finding properties for substances at or near a liquid-vapor phase change (hereafter referred to as "steam", although the discussion applies to other substances near a phase change including refrigerants). The methods used for finding steam properties have evolved over the last century, from reading charts and graphs, to tables, to more modern methods of computer-aided calculators, and now potentially into using AI tools. In this paper, the benefits and detriments of using these different methods will be discussed. Following that, some comments on the use of modern tools for other substances will be made.

Description of the Thermodynamic Property Needs

First-semester courses in thermodynamics tend to center on the first and second laws of thermodynamics. While the conceptual heart of the course is these laws, engineering students need to be able to obtain and use thermodynamic property data to apply the laws to engineering problems While complications for finding property data in solids/liquids and gases that arise in non-idealized substances can be introduced in introductory thermodynamics courses, much of the problem solution methods for these single-phase substances assume idealized behavior: assuming solids or liquids behave as incompressible substances and assuming ideal gas behavior for gases. In both cases the specific heats of the substances can either be assumed to be constant or the variability of the specific heats can be included in a problem solution.

Due to the rapidly-evolving nature of the properties of substances that are near or undergoing a phase change (such as water or refrigerants), simplification of property relationships is not a preferred analysis option. As a result, when dealing with substances that might change phases (typically between a liquid and a vapor for mechanical engineering), students will need to rely on means other than simple equations to find necessary properties such as specific volume, specific internal energy, specific enthalpy, and specific entropy.

Many years of teaching introductory thermodynamics courses by the author have led to the observation of two primary difficulties that engineering students encounter when they attempt to apply property relationships to solving thermodynamics problems. One often-observed difficulty is that students struggle to determine which approach should be employed to a particular problem. For example, a common mistake is for students to apply ideal gas relationships to any substance. A second difficulty is students learning how to find properties for those substances that don't use simple equations for the relationships; this is of most concern when finding properties for water/steam and refrigerants. As there are several approaches that can be used for finding such properties, it is helpful to recognize the advantages and disadvantages of each. This can help the instructor guide students towards an approach they are most comfortable with using. Below, several approaches to finding properties are discussed.

Charts/Graphs for Steam Property Values

The use of a chart or graph to find properties for steam has a long history in engineering, but has mostly fallen out of favor in today's classroom. Modern thermodynamics textbooks may still have some charts for steam (such as Mollier diagrams [1]), but much more attention is paid to presenting tables of property data. Charts are readily available to students on the Internet [1-4]. Figures 1 and 2 show some examples of these charts. Due to the difficulty in reading charts in a textbook, it is easy to conclude that these are rarely being used by students to obtain values when solving problems.

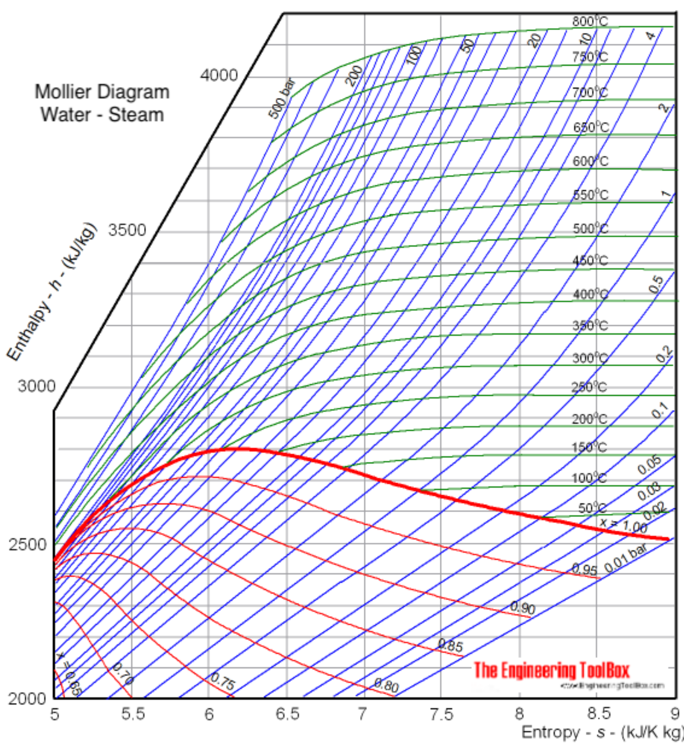

Figure 1: Example Mollier Diagram (h-s) for steam [1]

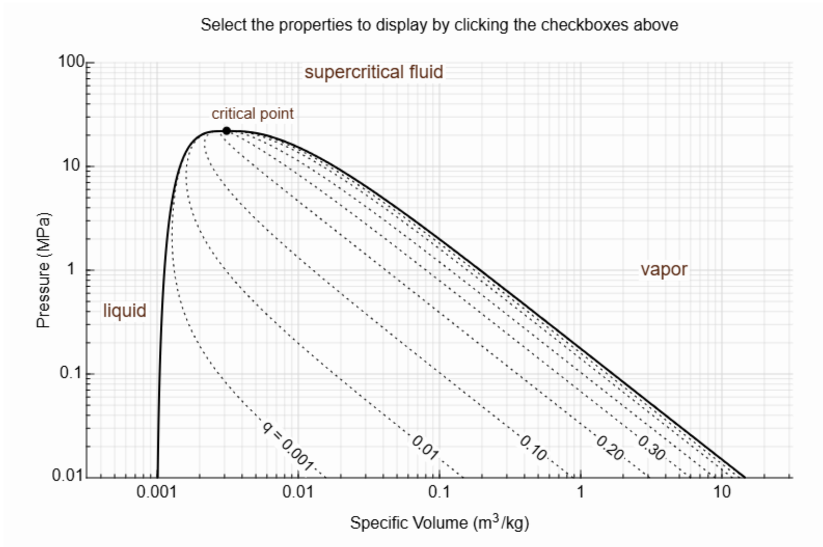

Figure 2: Example pressure-specific volume (P-v) diagram for steam [2]

The primary disadvantage of using charts for finding properties of steam is the lack of precision that is likely to result from a student using such a chart, and then the resulting range of answers that need to be considered correct when grading student work. Additionally, the condensed nature of some of the charts available to students in textbooks can make finding values frustrating for students. But is there still a place for charts in engineering thermodynamics courses?

There are two potentially beneficial aspects to using charts for finding steam property data or at least introducing students to the method of using charts. First, using charts can give students a visual aid in understanding how changing one property can affect the value of another property. While this can be approximated through free-hand drawing of how a property may vary, seeing multiple lines of constant values for a property on another diagram (such as lines of constant pressure on a T-s diagram) can help solidify students' understanding of the concepts. There is perhaps a more important lesson that can be learned by students from using charts for solving at least some problems: engineers often don't need the extreme precision of values that can be found from other techniques to develop a good design or perform a thermodynamic analysis. When students begin to assume that they need to have high degrees of precision (such as the 5 or more significant figures that may be available when using a table or computer program to get property data), they can miss the idea that there are unknowns in engineering or that conditions will vary. Engineers often design systems that handle a range of conditions, and having extremely precise values for properties such as specific enthalpy is not necessary. Having students become comfortable with the idea that using a specific enthalpy value of "2400 kJ/kg" is often just as workable for their design as "2382.53 kJ/kg" is something that will serve them well as they prepare for their careers. It is easier to get such a point across to students through using charts to find property data than it is through using other methods.

Tables for Water/Steam Property Values

An advancement that enabled students and engineers to obtain more precise values for steam properties was the use of tables [5,6]. A typical set of steam tables contains values of temperature, pressure, specific volume, specific internal energy, specific enthalpy, and specific entropy at discrete points. The data is generally divided into the liquid-vapor saturated region, superheated region, and compressed liquid region, with the possibility of liquid-solid saturation data, solid-vapor saturation data, and solid data also being available. The spacing between these points varies by steam table.

Linear interpolation is often used to find property data values for states that fall between the discrete points given in the tables. Thus, the accuracy of the result found depends on the spacing of the data in the tables.

For many years, students predominantly found steam data using the steam tables. While some students quickly learned how to extract data from the steam tables, other students spent weeks trying to master the processes and some never succeeded. As a result, students often grew frustrated with their thermodynamics course due to the difficulty they faced in finding the data to use in the problems they were attempting to solve. In turn, this has led to difficulty understanding the concepts of the course beyond finding property values.

Despite the availability of some of the techniques yet to be described, some students today still either are expected to use steam tables or choose to use steam tables when finding values. Many thermodynamics textbooks provide steam tables in an appendix, and steam tables are readily available on-line as well [7,8].

Using steam tables allows students to rather quickly obtain very precise values for thermodynamic properties, leading to less error than the students will introduce into their solutions from attempting to read property values off of a chart. (This assumes that the students obtain a reasonably correct value from either the tables or charts.) Additionally, by seeing a large set of values for properties, students can gain an appreciation of the magnitude difference between values at different states (for example, how much specific enthalpy change is encountered when boiling water at low pressure vs. high pressure). Students can also get a sense of how property values change as another property is changed, although this might more easily gained through seeing the data plotted on a chart. Whether a student gains these appreciations depends on the student and how interested they are in exploring the data in the tables.

There are a couple of clear disadvantages to using tables for finding property values. First, as mentioned, many students have struggled to master the techniques needed to extract data from steam tables. This can hinder their understanding of the primary principles taught in the course, as they spend more time trying to find property data rather than learning the intricacies of the laws of thermodynamics. This can lead to students disliking the subject, and propagating that dislike to future students in the course who then enter the course fearing its difficulty. The second disadvantage is that the extra precision gained from using tables can give students a false sense of the precision of their answer. While given property data may be known to only 2 or 3 significant figures of precision, students will still find a value with 5 or 6 significant figures of precision from the tables and then present that in their final answer. For example, students may end up claiming that a steam turbine with an inlet temperature and pressure of 525°C and 8.75 MPa produces 131.5328 MW of power. While this may be what was calculated, it is clearly not in good engineering form to provide such precision in an answer. It is still possible to do this with values read from a chart, but the imprecise nature of data from a chart can help remind students of how well they actually know the values they are using.

Computer Programs / Apps

While not a new development, the spread of computers into everyday life has opened a new method for students to obtain thermodynamic properties. Students can use software tools for finding properties of common substances such as steam. These tools can come in many forms, including dedicated software packages, property calculators on Internet websites [9,10], plug-ins for other software programs such as MATLAB [11], and apps on cell phones. While this approach has been available for a few decades, the ubiquitous presence of smart phones has turned this approach into a readily-available method for engineering students to use in the classroom or while working on homework.

Recognizing that today's students were very comfortable with technology, the author has changed his approach for teaching how to find steam properties to encourage students to use inexpensive phone apps or free Internet websites to find property data while also explaining how to use the steam tables and giving students some practice with using steam tables. The author allows the students to choose which approach they prefer to use. Somewhat surprisingly, a portion of the students choose to continue to use the tables and are hesitant to use computer programs or apps. Conversations with some of these students have indicated that those who choose to use steam tables typically are concerned with not being able to use the phone apps or Internet programs on a test. (To prevent easy cheating/collaboration on tests, students are not permitted to use computers or phones while taking the test.) Therefore, they choose to only use steam tables, despite being assured that the tests will be solvable with only a minimal knowledge of steam tables. (The author provides the values that the students need to solve the problems provided they know the correct variable to use. Figure 3 shows an example of how steam property data is provided in a test question.) This continues even after the students take the first test and see the format of the test questions – some students remain hesitant to simply use the software methods available to them.

The primary advantage to using a software tool for finding steam properties is that students do not need to master learning the tables – in particular they do not need to know how to interpolate between values. Additionally, students can spend less time finding property data while working problems. In turn, this also allows students to either have time to work more problems or to dive more deeply into the results of a particular scenario and their meaning. One problem type that this makes more solvable for students is a parametric analysis. For example, rather than solving a steam turbine problem based on one set of given inlet and outlet conditions, students can now be asked to solve a steam turbine problem while varying one of the given properties so that they can see how that property impacts the performance of the steam turbine. Doing this gives the students a better understanding of the relationships between properties and performance and

Steam flows through an insulated turbine at a rate of 180 kg/s. The steam enters the turbine at 10 MPa, and 510°C, and exits the turbine at 600 kPa. The isentropic efficiency of the turbine is 0.82. Determine
(a) the actual specific enthalpy of the steam at the exit (give answer to 5 significant figures), and
(b) the power produced by the turbine (in kW or MW).

Superheated Steam Data:

T(°C)	P (MPa)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg-K)
510	10	3066.8	3400.8	6.6324

Saturated Water Data:

P (kPa)	u_f (kJ/kg)	u_g (kJ/kg)	h_f (kJ/kg)	h_g (kJ/kg)	s_f (kJ/kg·K)	s_g (kJ/kg·K)
600	669.9	2567.4	670.6	2756.8	1.9316	6.7609

Figure 3: Example test question from the author showing a typical presentation of steam property data on a test in the author's class.

allows them to gain insights into thermodynamics that they may be able to use in their careers. While these problems can be solved using hand calculations with steam tables, the process of finding properties by typing in a new value into a computer program or app is much quicker and less cumbersome for the students – opening the potential for more learning.

A disadvantage of using computer programs for finding steam property data is that the values of the properties delivered tend to be provided at even greater precision than steam table data. This has the same problem for students as it did for steam tables, only potentially worse. A second disadvantage to using computer programs is that the students are essentially using a black box – they input values and are given an output value. While mistakes can always be made with using the wrong data from steam tables, this black box approach does open up more potential for a student not noticing that a value did not make sense and that a mistake may have been made while entering the data (or that the program itself is in error).

As mentioned, the author has adopted an approach of encouraging students to use computer programs while still giving an option of using steam tables. The author has observed that fewer students are struggling with finding steam properties than when all students were using steam tables. Those who do struggle tend to be the ones who are still choosing to use steam tables, and the students using the steam tables tend to voice more frustration with finding property values than those using computer programs. As a result, more time can be devoted to learning the thermodynamics aspects of the problems and less time spent on property calculations. Conversely, there does seem to be somewhat of a decrease in the understanding of the different states of water, particularly regarding how the quality of a saturated mixture can be of use in finding property data.

Artificial Intelligence Tools

As artificial intelligence (AI) tools became very popular in the last few years, the author chose to explore whether they could be useful for finding thermodynamic properties. A brief trial attempt with using ChatGPT demonstrated that AI could be used to quickly provide thermodynamic property data for steam and other substances. The query format that was used was rather cumbersome (in comparison to a calculator-like interface as used by most of the software tools), but with more expertise in AI the input could likely be simplified. Another drawback was that the tool used tended to give a long explanation of how to find the property values, rather than just providing the values; however, the author found a method to suppress this unwanted explanation. The results of this initial trial were encouraging.

The author, however, soon found some serious shortcomings with the tested AI tools beyond the cumbersome interface. The exploration of using AI was expanded to also include Google Gemini and Microsoft Co-Pilot. The shortcomings are explained in more detail below, but briefly the tools provided inconsistent answers, often gave approximate answers, sometimes incorrectly determined the state of the steam, and at times returned multiple possible answers depending on whether the steam was a saturated mixture or a superheated vapor (instead of determining the actual state of the steam).

Table 1 contains the results provided by the three AI tools for multiple queries for the same steam property at a specific state. The trials were performed in November 2025. Note, the values returned by the different AI tools may be considerably different depending on what data source the tool is using for its calculations, and what that particular data set used for an arbirtrary 0-point for the specific internal energy. However, the change in a relative property such as specific enthalpy between two states should be very similar regardless of the data set employed.

Considering the results shown in Table 1 for these four queries, there are several concerning trends that emerge with the use of AI tools. A very clear problem that all three AI tools have, but is most problematic with Google Gemini, is a lack of consistency in the property values returned by the tool. A possible explanation for this is that the tool may be mining data from different data sets for different trials for answering a query. The lack of consistency certainly raises issues in problem solving. What value should a student use? Should a student run 5 or 10 trials of the same query until it finds a consistent result? And then is that the right value? If the values are slightly different for each trial (for example, the specific entropy values returned by Google Gemini in the fourth query in Table 1), there likely won't be a major error in any resulting calculation. But larger inconsistency can clearly lead to issues with problem solving or design.

Another flaw of the AI tools is that they typically are not returning values that are "correct", with respect to current steam table results. If the results are consistently incorrect, that is not necessarily a problem for some properties that are relative to an arbitrary 0-point. For example, if you are seeking to calculate a change in specific enthalpy between two states, and the AI tool uses a data set that has a different reference state than another set of steam data such that all the values differ from another data set by the same amount, then the difference between the two values for the two different data sets will still be the same. But that is not the case here. For example, for the three queries involving specific enthalpy values, ChatGPT values differ from the steam tables value by ~60 kJ/kg, ~80kJ/kg, and ~300 kJ/kg. Therefore, the resulting changes in specific enthalpy will be incorrect, leading to incorrect answers for a first law of thermodynamics analysis using enthalpy.

Table 1: Sample results provided by three AI tools to different steam property queries. Each request was made to the AI tool three times within a 5-minute period.

AI Tool	Trial 1	Trial 2	Trial 3	Comments
Query 1: Specific Enthalpy of Water at 400ºC and 1200 kPa (Steam Table Value: 3261.2 kJ/kg)				
Google Gemini	~3105 kJ/kg	3325 kJ/kg	~3330 kJ/kg	Inconsistent/wrong
MS Co-Pilot	~3215 kJ/kg	~3215 kJ/kg	~3215 kJ/kg	Consistent
ChatGPT	~3200 kJ.kg	~3200 kJ/kg	~3200 kJ/kg	Consistent
Query 2: Specific Enthalpy of Water at 1.25 MPa and s = 4.2 kJ/kg·K (Steam Table Value: 1716.9 kJ/kg)				
Google Gemini	1728.4 kJ/kg	1719.06 kJ/kg	1676.73 kJ/kg	Good, but inconsistent
MS Co-Pilot	3100-3150 kJ/kg or 2050 kJ/kg	2050 kJ/kg	2050 kJ/kg	First trial unable to determine the state. Then consistent but incorrect.
ChatGPT	~3160 kJ/kg	1800 kJ/kg	1800 kJ/kg	First trial – couldn't figure out how to find the phase.
Query 3: Specific Enthalpy of Water 1.25 MPa and s = 7.2 kJ/kg·K (Steam Table Value: 3157.0 kJ/kg)				
Google Gemini	3068.98 kJ/kg	2960.3 kJ/kg	3046.25 kJ/kg	Inconsistent
MS Co-Pilot	3220 kJ/kg	3220-3250 kJ/kg	3230-3260 kJ/kg	Range of values isn't helpful
ChatGPT	3470 kJ/kg	3470 kJ/kg	3470 kJ/kg	Consistent, but incorrect
Query 4: Specific Entropy of Water at 150ºC and v = 0.25 m^3/kg (Steam Table Value: 5.02 kJ/kg·K)				
Google Gemini	4.94 kJ/kg·K	5.0167 kJ/kg·K	4.986 kJ/kg·K	Inconsistent
MS Co-Pilot	~4.9 kJ/kg·K	4.72 kJ/kg·K	4.72 kJ/kg·K	Inconsistent, low
ChatGPT	4.59 kJ/kg·K	4.59 kJ/kg·K	4.59 kJ/kg·K	Consistent, incorrect

A third problem with the AI tools showed up in two of the queries/trials in this limited test: the tools could not always determine how to properly analyze the information given in the query to find the state. For Trial 1 of Query 2, Microsoft Co-Pilot provided two values for the specific enthalpy; one was for the state being a superheated vapor and one for it being a saturated mixture. Clearly, it is one or the other (in this case it is a saturated vapor), but from the information given it could not determine the state. It did not have this problem in the next two trials, but if this becomes a regular occurrence, students will become frustrated trying to use the AI tool. The second case was with Trial 1 of Query 2 with ChatGPT. Quoting from the explanation the tool provided in returning the result, "At 1.25 MPa (12.5 bar) and s = 4.2 kJ/kg·K, the state of water is superheated vapor (since saturated vapor entropy at 1.25 MPa is ~ 6.7 kJ/kg·K)." The tool was concluding that because $s < s_g$ (or because the two values weren't equal), the state was superheated vapor. This is completely wrong as the state should be a saturated mixture. Again, providing wrong information to the students is unproductive, and potentially dangerous.

It should be noted that there is potentially a major flaw with the approach that AI is often taking to find answers – scouring the Internet and use what it concludes is the best result. If AI concludes that false information is best, that is what it will inform the user. This can lead to confusion for the students or could lead to wrong results in practice by an engineer using such a tool. Consider what might happen if a nefarious actor decided to flood the Internet with false methods for analyzing information or false property data. An unwary user may take the results given as being true and make a major design mistake based on that false data.

A last point to be made is that many of the simple queries to AI tools result in lengthy explanations as to how to find the value. Seeing this repeatedly would likely become annoying for a user, but this can also be suppressed with additional instructions in the query. However, that makes the query longer and more time-consuming to write.

With these shortcomings, it is not possible to recommend the use of AI by engineering students (or practicing engineers) to find steam properties at this time. But it should be noted that AI tools are evolving rapidly, so that it is possible that this recommendation will be out-of-date within a few years. Considering the very specialized nature of the application of finding thermodynamic properties, it may not be realistic to expect general AI tools to quickly overcome the shortcomings found. Perhaps the development of a dedicated AI tool for finding thermodynamic properties would be the quickest way to make AI produce acceptable results. As noted, general AI tools also run the risk of relying on bad data added to the Internet; a dedicated AI tool for finding properties may be able to avoid the potential use of poor data. This description begins to look like a different version of dedicated property calculators which already exist. And compared to dedicated property calculators with well-developed user interfaces, it is likely to remain cumbersome to use AI tools for the foreseeable future.

However, one area that could become a good use of AI tools is finding properties for less common substances. Such substances aren't likely to have substantial resources devoted to creating programs with easy-to-use interfaces for finding properties. But AI could be used to seek out and find reliable property data for many less common substances. All the AI tools really need is to have the data available to the public on the Internet and have enough understanding of thermodynamics to be able to give good answers to property data queries.

If AI tools develop to the point where they are easily and quickly providing accurate values for thermodynamic properties, thought needs to be given as to how to best use these tools from an educational standpoint. Students will still need to understand relationships between properties and recognize reasonable values for properties and property changes so that they can properly interpret calculation results and create well-designed products. Therefore, such future AI tools might best be used as a method of simplifying the process of getting property data and allowing students to focus more time on understanding the underlying thermodynamics.

Considerations for Other Substances

When finding properties using computing technology for substances experiencing phase changes other than water, much depends on the availability of data. Some apps and websites exist that can be used for finding thermodynamic property data for various refrigerants, but these appear to be less commonly available than those for water/steam properties. Still, as the options continue to evolve, this should be considered as a useful approach to encourage students to take, rather than relying solely on tabulated data.

For substances that are not undergoing a phase change, there is generally less need to be as concerned with using computers to find the properties as a reasonable engineering analysis can usually be done employing a constant specific heat approach (with an appropriate choice of the temperature to use for the value of the specific heat). Additionally, tables containing property data based on variable specific heats for such substances tend to be simpler to use than steam tables for students. As such, using tabulated data either on paper or on-line is generally going to be sufficient for the occasions when students need to consider variable specific heats in their analysis. Some calculators for common substances that are unlikely to undergo a phase change, such as air, are also available to students if needed.

Summary

In this paper, various methods that students can use for finding thermodynamics properties were reviewed, with a particular emphasis on steam property data. Advantages and disadvantages of using charts/graphs, tables, and computer programs or apps were discussed. From this, a good approach to use with teaching students about steam properties and how to find properties may be a combination of using graphs to show the general property trends and then encouraging the use of computer programs to perform the calculations to provide a value for steam properties.

Initial trials of using three AI tools were summarized, and it was clear that the tools are not ready for reliable use to find steam property values. This does not mean that the tools can't be trained and improved such that they do become useful in this task in the future, although for some time they likely will remain more cumbersome to use than a dedicated computer program with a good user interface. But at this time, the use of AI tools is likely to cause more harm than good for students. Furthermore, in the near future one must remain conscious of the fact that the tools will rely on what is available on the Internet, and AI tools may be able to be manipulated into providing poor results.

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