Web-Based Thermodynamics Tables Wizard

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Abstract

In the study of Thermodynamics, looking up thermodynamics properties from tables has been an essential skill that students need to acquire. Since more higher education institutions are now offering online courses or Web-teaching, the challenge that one faces is how to make use of the multimedia technology to teach students to use thermodynamics tables and facilitate the properties look-up process via the Web.

This paper presents the Web-based Thermodynamics Tables Wizard and how it can be used to accommodate the needs of students at different levels in looking up thermodynamics properties. For students in their early stage of study, interactive workshops are provided for them to study the basic relations among various thermodynamics properties when using the tables. In addition, an interpolation tool along with interactive thermodynamics tables has been designed to minimize the computational effort. Another feature of this wizard, which is especially designed for more advanced students, is its built-in thermodynamics functions which allow students to obtain thermodynamics properties without the need of tables. This Thermodynamics Tables Wizard can be used as a stand-alone studying aid or an add-on component for any online Thermodynamics course. The implementation of this Web-based module can greatly enhance the learning experience of students when they study Thermodynamics.

I. Introduction

In the study of thermal sciences, acquiring thermodynamics properties has been an essential part of problem solving. Thermodynamics properties are most often presented in a tabulated form and are included in a thermodynamics textbook[1-3]. They are also available in several commercial packages which sometimes are distributed through the sale of a textbook. For example, through the distribution of thermodynamics textbook by Moran and Shapiro[1] is a software package called Interactive Thermodynamics (IT)[4] developed by IntelliPro, Inc. Similarly, the textbook by Sonntag et al.[2] comes with a software package called Computer-Aided Thermodynamics Tables

2 (CATT2)[5] which is also developed by IntelliPro, Inc. Another popular thermodynamics textbook by Çengel and Boles[3] has supplements such as the Engineering Equation Solver (EES)[6]. The commercial package of EES is developed by F-Chart Software and the license of this software is distributed by McGraw-Hill for educational institutions. All these software packages have been supplied in the form of compact disk. They are generally very helpful for students and engineers in solving problems of thermodynamics and related subjects. However, little effort has been devoted so far to develop interactive ways of delivering thermodynamics properties through the Web despite the recent advocate of online engineering education, which takes advantage of the dramatic dynamics and spectacular visualization that multimedia technology has to offer. Therefore, it is our objective to deliver thermodynamics tables effectively through the Web and let students have a positive experience in learning Thermodynamics online.

II. An Overview of the Thermodynamics Tables Wizard

As shown in Figure 1, this Thermodynamics Tables Wizard consists of four separate modules: (a) workshops, (b) interpolation module, (c) advanced user module, and (d) unit conversion module. This Thermodynamics Tables Wizard is now available online, and it can be accessed at the following URL, http://coecs.ou.edu/flai/www/Wizard/wizard.htm. This wizard was designed
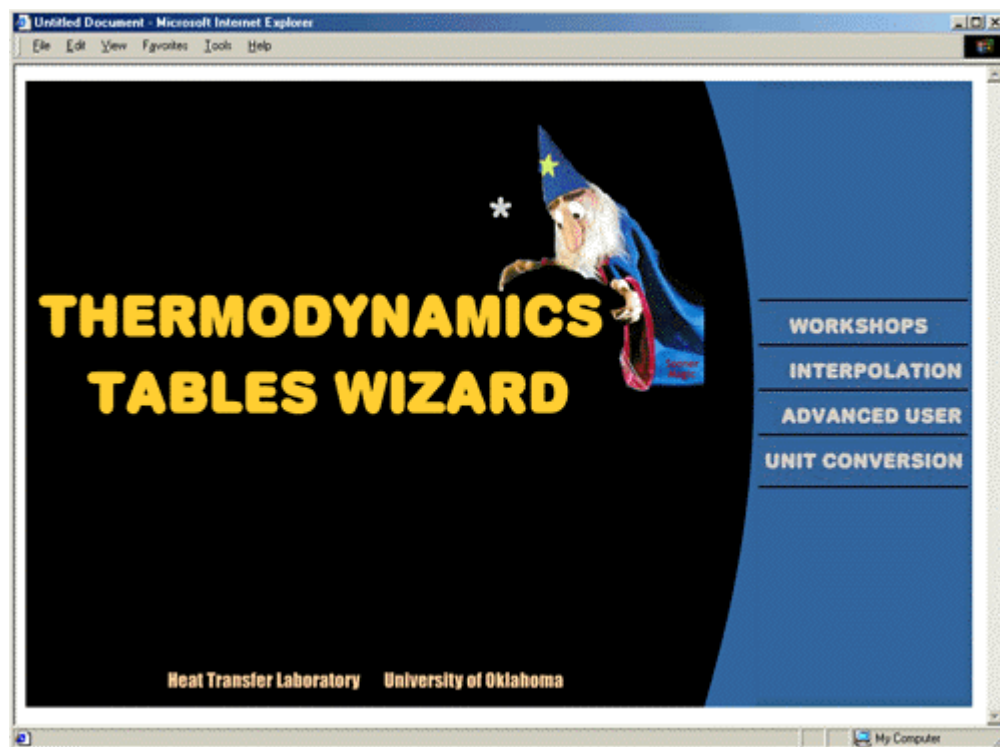

Figure 1. Main Page of the Thermodynamics Tables Wizard.

in such way that it could meet the need of students at different stages of their study. Most of the modules (workshops, interpolation module and advanced user module) in this Thermodynamics Tables Wizard were created using Macromedia Flash 5 whereas the unit conversion module was developed using Director 7. The advantage of using Flash is that the generated Flash Player movie file (.swf) is usually small in size, and hence can be easily downloaded through the Web. Each of these modules will be discussed in more detail in the following sections.

III. Workshops

Usually, students are taught to look up thermodynamics properties from the tables in their early lessons of Thermodynamics. To ensure that students can acquire this important skill, five interactive workshops (Figure 2) have been provided for them to become familiar with the use of thermodynamics tables. These workshops were first implemented in a thermodynamics course page[7] at the University of Oklahoma and have since gained favorably responses from the students. These five interactive workshops were mainly designed to teach students how to use the thermodynamics tables such as the saturated water tables (temperature and pressure tables), superheated vapor table and compressed liquid table. The objective of this particular module is to improve students' basic understanding of the interrelations of thermodynamics properties. In each workshop, students are directed to a series of step-by-step instructions. Through these

Figure 2. Workshops Interface.

workshops, students will also learn to interpolate the tabulated values if needed. Interactive workshops such as these provide a more effective way of engaging students in learning as compared with a lengthy illustration commonly found in a textbook.

IV. Interpolation Module

The interpolation module consists of the automated thermodynamics tables for saturated water (temperature and pressure tables), superheated vapor, compressed liquid and air (as an ideal gas). They were adopted from the textbook by Çengel and Boles[3]. The objective of this module is to provide the students with an access to the thermodynamics tables via the Web and facilitate the interpolation process. Figure 3 shows the interface of the interpolation module.

For example, if a student is asked to find the value of v_f from the saturated water pressure table when u_g is given as 2425.5 kJ/kg, he can simply input the two sets of properties which form an envelop in u_g by clicking on the corresponding values from the saturated water table (for this particular case, they are u_g = 2420.5 kJ/kg and v_f = 0.001005 m^3/kg along with u_g = 2430.5 kJ/kg and v_f = 0.001008 m^3/kg) and have them transferred into the fields of the interpolation interface on top of the table. The student will then be asked to enter the known value of internal energy (u_g = 2425.5 kJ/kg). After all required fields are entered, he can click on the arrow button. The

INTERPOLATION

Saturated Water (Pressure)

Int. Energy (g)	Spec. Vol. (f)
2420.5	0.001005
2430.5	0.001008

Int. Energy (g): 2425.5 → Spec. Vol. (f): 0.0010065   Reset

SATURATED WATER (PRESSURE) TABLE

P (kPa)	T (°C)	Specific Volume (m³/kg)		Internal Energy (kJ/kg)			Enthalpy (kJ/kg)			Entropy (kJ/kg·K)		
		v_f	v_g	u_f	u_{fg}	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
0.6113	0.01	0.001000	206.14	0.0	2375.3	2375.3	0.01	2501.3	2501.4	0.0000	9.1562	9.1562
1.0	6.98	0.001000	129.21	29.30	2355.7	2385.0	29.30	2484.9	2514.2	0.1059	8.8697	8.9756
1.5	13.03	0.001001	87.98	54.71	2338.6	2393.3	54.71	2470.6	2525.3	0.1957	8.6322	8.8279
2.0	17.50	0.001001	67.00	73.48	2326.0	2399.5	73.48	2460.0	2533.5	0.2607	8.4629	8.7237
2.5	21.08	0.001002	54.25	88.48	2315.9	2404.4	88.49	2451.6	2540.0	0.3120	8.3311	8.6432
3.0	24.08	0.001003	45.67	101.04	2307.5	2408.5	101.05	2444.5	2545.5	0.3545	8.2231	8.5776
4.0	28.96	0.001004	34.80	121.45	2293.7	2415.2	121.46	2432.9	2554.4	0.4226	8.0520	8.4746
5.0	32.88	0.001005	28.19	137.81	2282.7	2420.5	137.82	2423.7	2561.5	0.4764	7.9187	8.3951
7.5	40.29	0.001008	19.24	168.78	2261.7	2430.5	168.79	2406.0	2574.8	0.5764	7.6750	8.2515
10	45.81	0.001010	14.67	191.82	2246.1	2437.9	191.83	2392.8	2584.7	0.6493	7.5009	8.1502
15	53.97	0.001014	10.02	225.92	2222.8	2448.7	225.94	2373.1	2599.1	0.7549	7.2536	8.0085
20	60.06	0.001017	7.649	251.38	2205.4	2456.7	251.40	2358.3	2609.7	0.8320	7.0766	7.9085
25	64.97	0.001020	6.204	271.90	2191.2	2463.1	271.93	2346.3	2618.2	0.8931	6.9383	7.8314
30	69.10	0.001022	5.229	289.20	2179.2	2468.4	289.23	2336.1	2625.3	0.9439	6.8247	7.7686
40	75.87	0.001027	3.993	317.53	2159.5	2477.0	317.58	2319.2	2636.8	1.0259	6.6441	7.6700
50	81.33	0.001030	3.240	340.44	2143.4	2483.9	340.49	2305.4	2645.9	1.0910	6.5029	7.5939
75	91.78	0.001037	2.217	384.31	2112.4	2496.7	384.39	2278.6	2663.0	1.2130	6.2434	7.4564

Figure 3. Interpolation Module Interface.

module is encoded to perform a linear interpolation (Eq.1) between the two sets of properties that were entered earlier and return the desired result.

$$v_f = 0.001005 + \frac{2425.5 - 2420.5}{2430.5 - 2420.5}(0.001008 - 0.001005) = 0.0010065 \text{ m}^3/\text{kg} \qquad (1)$$

This module will not only facilitate the interpolation process for students, but also provide them the opportunity to familiarize themselves with the usage of thermodynamics tables at the same time.

V. Advanced User Module

When dealing with design or open-ended problems (such as those of power cycles), students are often required to do interpolations repeatedly to obtain properties at different states. This property-look-up process can become very tedious and sometimes may divert the student's attention from learning the underlying principles that a particular problem would have conve yed. Therefore, an advanced user module was created to facilitate the number crunching process for those students who have already mastered the basic relations of thermodynamics properties.
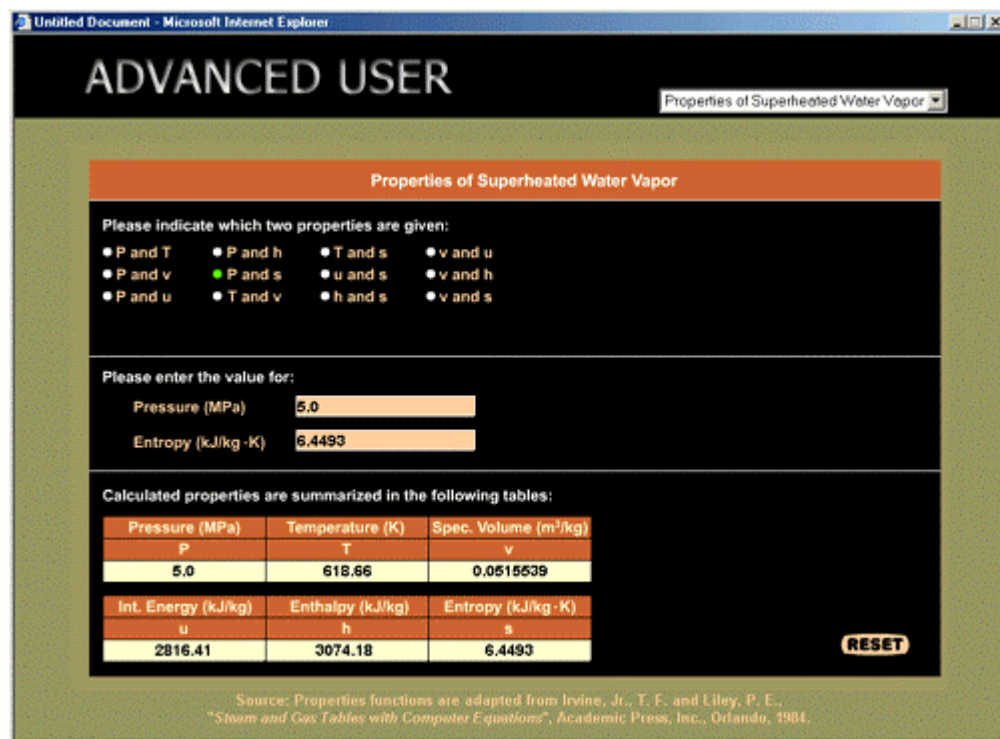

Figure 4. Advanced User Interface.

This advanced user module (Figure 4) has built-in thermodynamics functions which allow students to obtain thermodynamics properties without resorting to the tables. With this advanced user module, students can obtain the properties of saturated water, superheated vapor, and air as an ideal gas directly. All built-in functions in this module were adopted from the work published by Irvine and Liley[8]. For saturated water, the properties are expressed as a function of either saturation temperature or pressure. For superheated vapor, they are a function of both pressure and temperature while for air as an ideal gas, they are a function of temperature only. To be flexible, the module allows students to obtain thermodynamics properties using any input other than the temperature or pressure. To implement this option, Newton-Raphson method[9] with a convergence criterion of 0.01% was used to solve the functions mentioned above. It should be noted that great care has been taken in assigning the initial guessed value to ensure the convergence and accuracy of the results.

The equations of the built-in functions and the programming details are omitted here for brevity and readers can refer to the work of Irvine and Liley[8] for an in-depth discussion. However, there are a few things that need to be addressed here. For air, the entropy data used in this module are based on the standard entropy at 0.1 MPa pressure, which are different from those published by Keenan and Kayes[10] that use the absolute zero temperature as the reference state. Since it is the difference in the entropy that is important in most problems and applications, there is no major loss due to this slight difference in the reference state of entropy. Also for the superheated vapor, the internal energy and enthalpy are a strong function of temperature. An input using the combinations of (t,u), (t,h) and (u,h) thus becomes dependent and produces compromised results. Therefore, the option of using these combinations of properties as an input is eliminated from this module.

Students will benefit greatly from this advanced user module when solving design and open-ended problems. By saving their time from the number crunching process, they can better focus on the underlying principles.

VI. Unit Conversion Module

In recent years, the metric SI system has become the worldwide standard unit system in the engineering and scientific community. Therefore, only the SI units are employed in this Thermodynamics Tables Wizard. However, the transition from English system to SI system is still in progress in the United States and English units remain popular in industry. For this reason, most thermodynamics textbooks continue to use both systems (although a greater emphasis is placed on the SI units). To accommodate the transition in unit systems and allow students to solve problems with both SI and English units when using this Thermodynamics Tables Wizard, a unit conversion module was developed to convert units from one system to another. Only units that are frequently encountered in the study of thermodynamics (e.g., pressure, temperature, and internal energy,…, etc.) are included in this module.
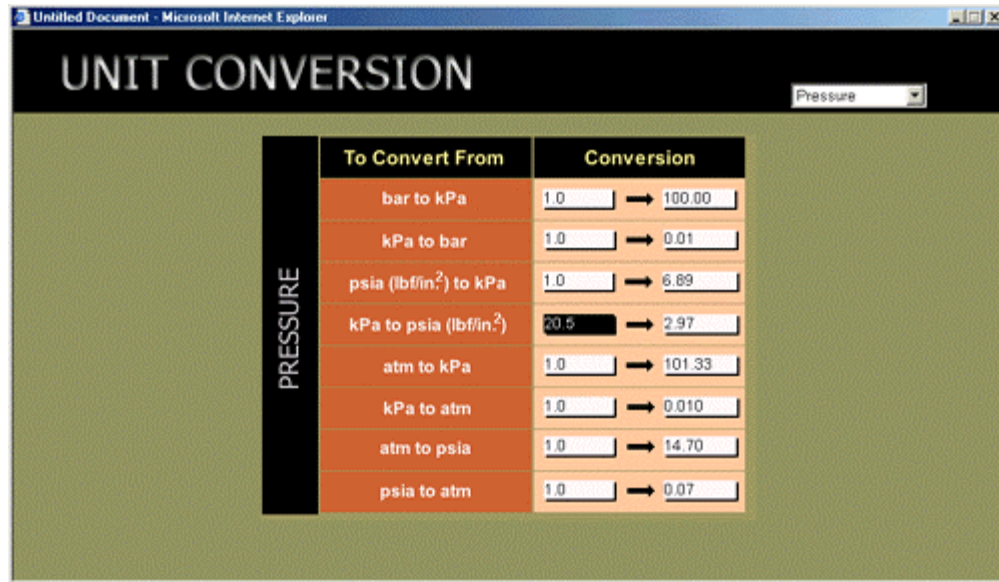
Figure 5. Unit Conversion Module Interface.

The unit conversion tables (such as the one shown in Figure 5 for pressure) were programmed using Macromedia Director 7 and Lingo, and saved in the Shockwave format for posting on the Web.   With this module, students can easily perform unit conversions when studying Thermodynamics.

VII. Conclusions

The Thermodynamics Tables Wizard presented in this paper evolves from a component that was originally implemented in an on-line Thermodynamics courseware[7] that the authors have been experimenting at the University of Oklahoma. Although it may not be as comprehensive as those commercial packages available on the market (such as CATT2, IT, or ESS), it does provide an effective way of delivering thermodynamics properties of the two most common working fluids (water and air) through the Web. It can be used as a stand-alone studying aid or an add-on component for any online Thermodynamics course. Based on the earlier responses from the students, we believe it will enhance their learning experience in studying Thermodynamics.   The follow-up evaluation of students' response will be conducted and reported in the near future.

Acknowledgement

References

1. Moran, M. J. and Shapiro, H. N., Fundamentals of Engineering Thermodynamics, 4th ed., John Wiley & Sons, New York, 2000.

2. Sonntag, R. E., Borgnakke, C., and Van Wylen, G. J., *Fundamentals of Thermodynamics*, 5th ed., John Wiley & Sons, New York, 2001.

3. Çengel, Y. A. and Boles, M. A., *Thermodynamics: An Engineering Approach*, 4th ed., WCB/McGraw-Hill, New York, 2002.

4. Interactive Thermodynamics (IT), IntelliPro, version 2, 2000.

5. Computer-Aided Thermodynamics Tables 2 (CATT2), IntelliPro, 2001.

6. Engineering Equation Solver (EES), F-Chart Software (http://www.fchart.com), Middleton, WI, 2002.

7. Ngo, C. C. and Lai, F. C., "Teaching Thermodynamics with the Aid of Web-Based Modules," Proceedings of the 2001 ASEE Annual Conference and Exhibition (CD-ROM), 2001.

8. Irvine, Jr., T. F. and Liley, R. E., *Steam and Gas Tables with Computer Equations*, Academic Press, Orlando, 1984.

9. Chapra, S. C. and Canale, R. P., *Numerical Methods for Engineers*, 2nd ed., McGraw-Hill, New York, 1988.

10. Keenan, J. H. and Kaye, *Gas Tables*, Wiley, New York, 1948.

Biography

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