Thermograf, a didactic tool for teaching and learning thermodynamics

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Abstract

The present paper gives a description of Thermograf, a *tool* that has been designed for teaching and learning thermodynamics using a graphical interface. Thermograf is a didactic tool that provides a learning environment designed for working with graphical analysis. It covers all of the most important topics in a basic Engineering Thermodynamics course, and works with a cognitive base to promote a meaningful learning.

Thermograf can be used in different situations, such as in classroom presentations, for self-learning activity and for solving a set of teacher's proposed exercises. The configuration of the screen shows relevant information about processes or cycles, allowing its very easy modification, so that it is possible to analyze energy, exergy, entropy balances, and Q and W calculations with a wide assortment of different substances and some other types of values (enthalpy, specific heats, etc.).

The manipulation of every object on the screen is very simple and powerful, so the student is able to build and analyze every change in a cycle, even in the very complicated ones, in real time and getting quick answer for any change on the screen. Besides, the tool has some specific resources for self-evaluation on some of the most important concepts of the matter. Moreover, this software program has some particular resources for self-evaluation regarding some of the most important concepts of the subject.

I. Introduction

The use of a specialized software as a didactic tool is common in almost every topic of engineering courses. This situation does not differ much when thermodynamics is considered. Generally, the most sophisticated software available is modeled to perform design options for industrial facilities and plant optimization,[1] more than to be used as what we could call didactic tools in a constructivist learning environment.

Programs such as *EES*[2] or *Interactive Thermodynamics*[3] are among the most broad-based educational software dealing with thermodynamics. This kind of tool makes it possible to evaluate properties of equilibrium states for different substances. Thus, the software derives a solution for a specific problem from a set of initial data or by editing appropriate equations that the user defines and solves with an incorporated solving procedure. In some cases, as in those mentioned above, this procedure allows changing the value of some variables such as input parameters, to obtain a set of results through an iterative process. The user can thereby analyze the effect of such changes in the behavior of the system. Eventually, the user may obtain as well some plots of these results.

Other programs such as *GasCAD*[4] or ALLPROPS[5] allow some interactivity using the mouse to draw different processes on the screen. However, they have limited features concerning this type of interactivity. Finally, a third group[5, 6] provides the ability to evaluate different properties by generating tables of the results. Currently, the internet[7, 8,9] offers many sites with applets that perform various calculations, or that provide a plug-in that can be added to other programs. Therefore, the resources for the use of graphical analysis of thermodynamic systems have been barely exploited. Nevertheless, the understanding of various thermodynamic concepts can be stimulated or enhanced with the use of these graphical representations, and even more so if an interactive and creative analysis of these graphics is allowed.

Historically, the representation and study of processes in thermodynamic diagrams have been a part of didactic strategies widely used in the classroom, and in textbooks. A few examples could be: a) the comparison of different types of compression or expansion processes with the graphical analysis of work, of shaft work and heat, b) the analysis of Carnot's cycle, and c) the analysis and optimization of Rankine or Joule-Brayton cycles. However, all of these analyses often have two important limitations:

- The graphic representation has a qualitative, approximated approach, with a lack of precision in scales and shapes.
- The difficulty to perform precise evaluations of the thermodynamic properties of substances makes it necessary to employ simple theoretical models that can be used in some cases when working with real analysis. These models are frequently overused in classrooms because they are easy to handle due to the simple analytical expressions that can be obtained from them. This fact confuses those students that get a distorted picture.

As an alternative, computers offer the possibility to perform graphics with a very precise calculation of thermodynamic properties and to analyze them in a variety of contents within the course work of engineering thermodynamics.

II. Objective and main features of Thermograf

In our initial studies exploring the educational potential of personal computers, we began by constructing a set of laboratory simulations[10] and tools[11]. These programs were well received by the students, proving that it would be worthwhile to design improved programs to be used not only in the computer classroom but also in regular lectures with a multimedia projector. We then switched from HyperCard on Macintosh to C++ to gain speed, and later moved to Java to ensure the use of the program regardless of the operating system used by students.

When designing Thermograf, our main goal was to create a graphical environment with a high interactivity level, and to add through experience a set of features to improve the original frame. For instance, most of the models[12] designed for different substances fit well only in a limited range that corresponds to the range of uses. To obtain a "real" appearance when a process is drawn on the screen, we needed to increase this range substantially using special fittings for all models and substances used. Thus, we would be able to draw different objects (for instance, reference isolines) in a wider region than the previous fit allowed.

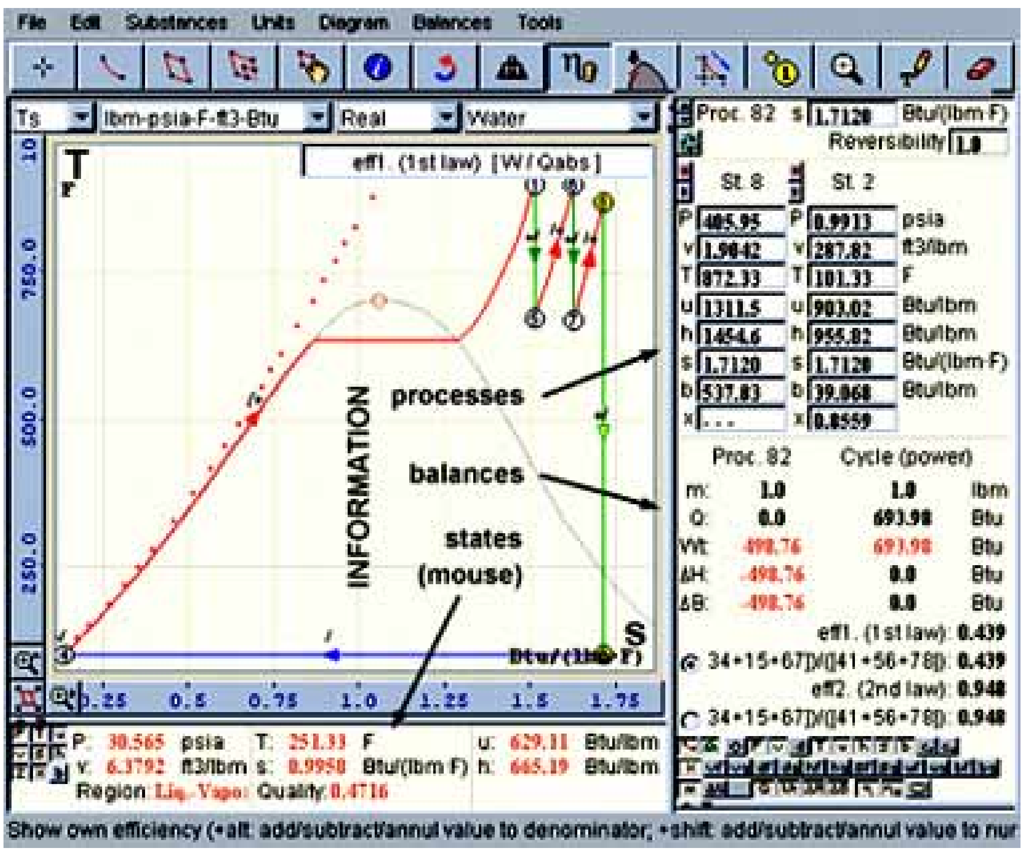

Figure 1.- General layout of Thermograf

The most recent version of Thermograf provides a powerful tool that works in a very interactive environment, with about 100 different possible actions performed pushing buttons or dragging the mouse. Furthermore, it is designed to be used in:

- Presentation of lectures with a projector
- Preparation of a set of exercises to be solved in a self-learning environment
- Performance of self-evaluation tests

The above can also be carried out with an adjustable configuration adapted to the expertise of the students (novices or experts). For that reason, the interface design, inspired in some drawing programs, is quite user-friendly with messages appearing at the bottom. All the above features allow the understanding of the system in just a few minutes of apprenticeship. This interface gives graphical and numerical information (figure 1), complete with a set of icons and all structured in well-defined domains pertaining to what is important in the analysis, such as mouse information, thermodynamic state properties, information on processes and evaluation of balances.

Users (teachers or students) have the possibility to configure the screen set up using the option **Prefs Thermograf** in the menu **File.** The window shown in figure 2 then opens, whereby it is possible to establish a wide set of characteristics or preferences, such as the system of units, the type of diagram, and much more.

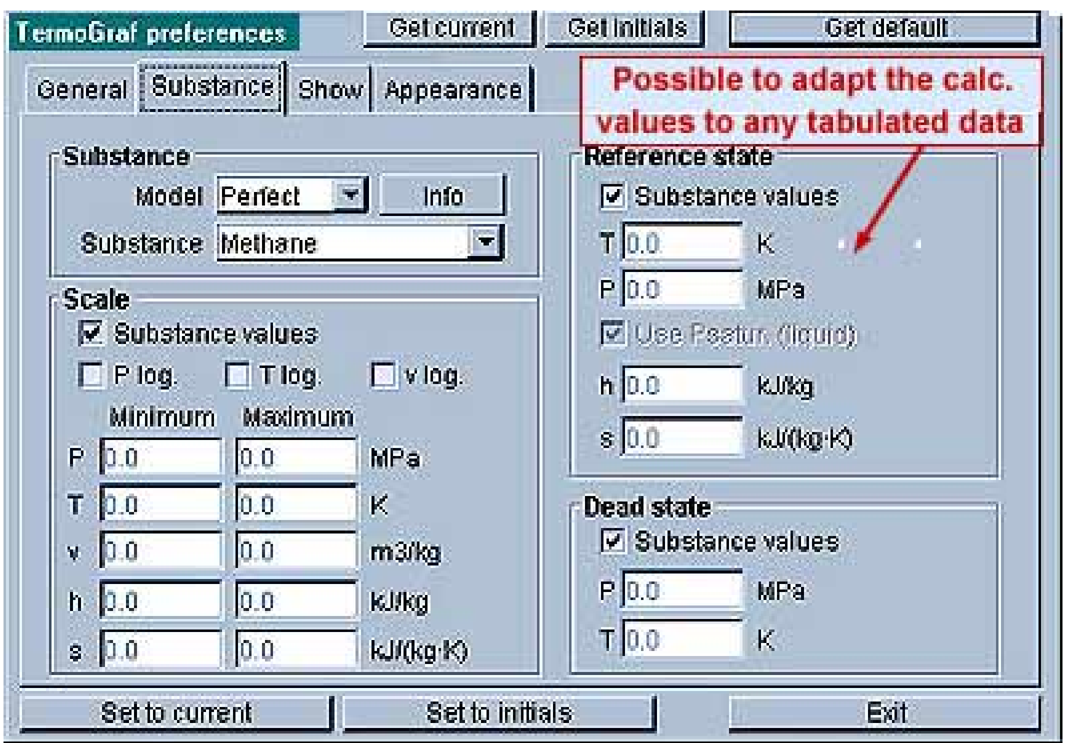

Fig. 2.- Window to set the preferences. It is possible to adjust the reference level for any substance

This feature is very useful in saving time when using it for classroom presentations, as those situations may differ significantly from one part of the contents to another. Similarly, documents can be prepared for self-learning so that the student determines the best-fitting configuration according to the situation of the course and his/her level of knowledge.

Cognitive overload is an important problem that can originate from having too much information on the screen. To reduce this problem and create an adaptive approximation to all the options of Thermograf, the Prefs option can be used to minimize the amount of data that the screen provides. Furthermore, the use of the menu bar and different sets of buttons allow the modification of the screen quickly and at any moment.

The program has been created in its current design, following the guidelines[13, 14] to design what we call a *specific general tool* for teaching and learning environments, such as GAME[15]. The specifications required for such a program are determined from the analysis of the transversal concepts, concepts that constitute the core of the subject considered and that are used along with most of its contents.

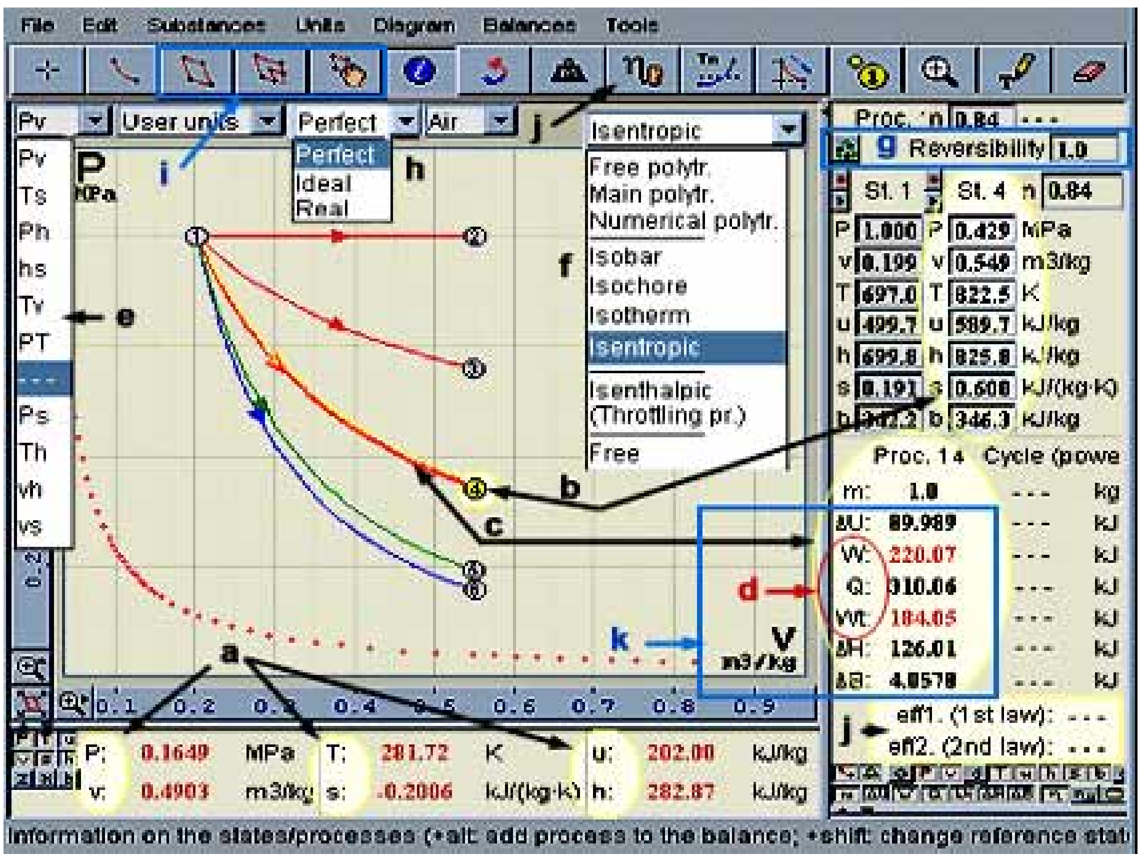

Fig. 3.- Different characteristics of Termograf. Colors in pads reflect the kind of process (see the explanation in text below)

In a basic course of engineering thermodynamics, these concepts are: a) thermodynamic properties, b) states, c) processes, d) process-dependent properties, e) diagrams, f) polytropic processes, g) reversibility/irreversibility, h) models of substances, i) cycles, j) efficiencies and k) balances (figure 3).

Those concepts also define the layout of the screen. Looking at figure 4, we can see the diagram as the main component (the size can be modified easily by the user adjusting the screen to his/her preference). The scale range can be defined in the corresponding window, but the user has other possibilities to include what he/she wants to plot: increasing or decreasing the upper limits of **y** and **x** coordinates by clicking the corresponding button (graph resolution control); sliding the scales by simply dragging each with the mouse pushed down or fitting all the completed plots by a click on the central button **a** of the graph resolution control (Figure 4). In addition, the user can zoom in and out with the magnifying tool that is very useful for analyzing some processes such as pumping in a Rankine cycle.

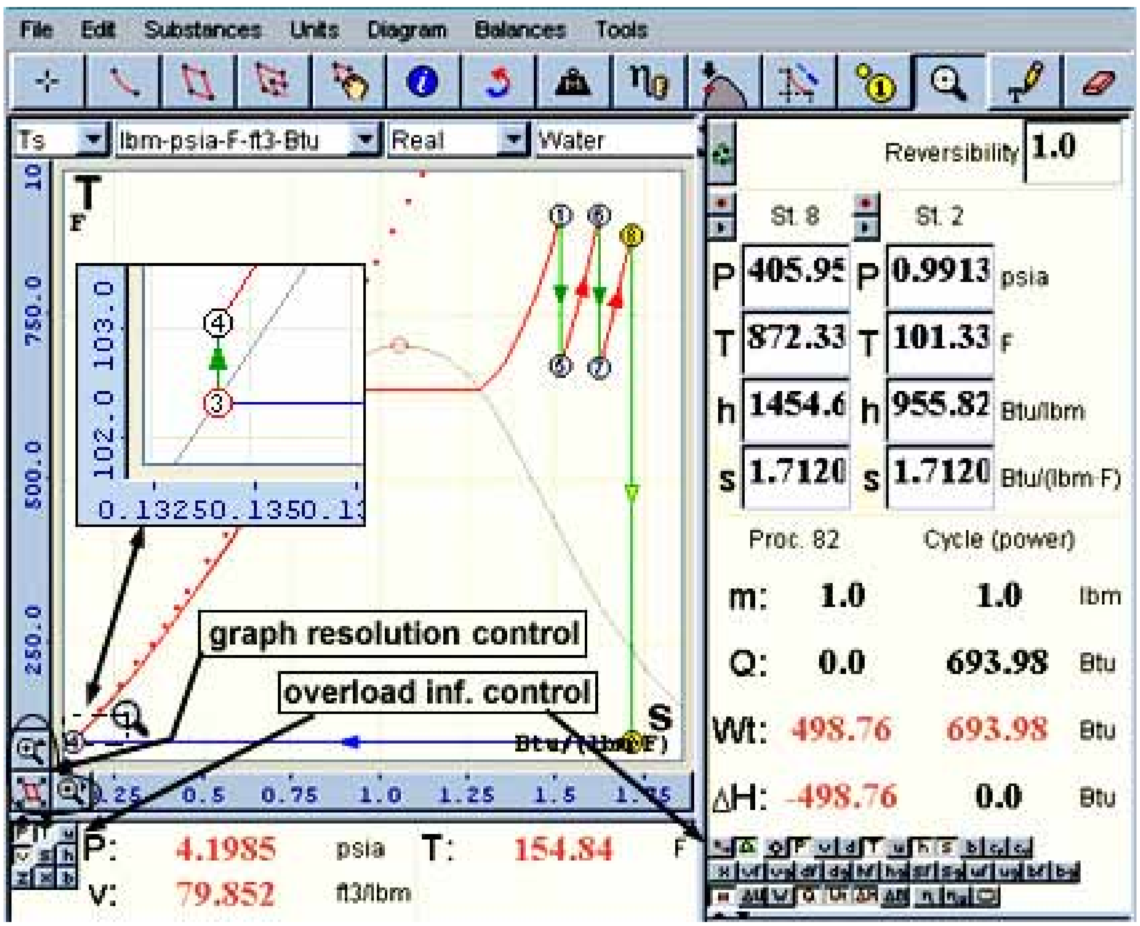

Fig. 4.- Layout for classroom presentation (minimum information)

Close to the diagram a set of thermodynamic properties reflects de value of the mouse pointer according to the selected diagram. A set of nine small buttons allows the user to adjust the number of properties so the overload information can be controlled by reducing the number of the objects changing in the screen (figure 4).

One of the most important features is the possibility of modifying in real time any plot created on the screen. This applies to single states, single processes or a combination of them, such as thermodynamic cycles. The didactic possibilities are so many that it is not feasible to cover them all in this paper. However, we can comment that most of the contents of a basic course were analyzed with Thermograf last year and many of the concepts could be worked out through simulation tasks. Complicated cycles are very easy to construct by combining processes with a simple mouse action. It is rather simple and requires only a few minutes to completely design any kind of cycle including the corresponding balances, making it possible to study how efficiency depends on different parameters, by simply dragging the objects characterizing these parameters (a singular state or a process). For instance, we can analyze the effect of pressure ratio on the performance of a Brayton cycle. This is one of the many possibilities that students can investigate utilizing these simulation tasks.

These possibilities allow the optimization of the time spent in lectures, laboratory or self-learning work. The student finds also several options for self-evaluation. For instance, he/she can determine if he/she knows how to operate, using concepts such as: a) thermal efficiency or exergy efficiency, in any kind of cycle, b) the balances in different heat exchangers located on these cycles, c) the distribution of mass when a flux is divided in several branches.

III. Future improvements and evaluation

The last feature that has been included introduces a combination of exercises with documents htm that allows different kinds of tests that suppose an important increase of the possibilities for self-evaluation. One more option we are considering for the program is the way to communicate with other programs so we will be able to open a multimedia material to complete the information analyzed in any of the proposed exercises. In addition, we are organizing a group of users to exchange documents for single simulation tasks or exercises that would help significantly the preparation of lectures.

Finally, we can say that students find working with Thermograf very interesting and stimulating. The results of the different tests show a very positive evaluation and some of the personal comments are very rewarding. Interestingly, students also pointed out that they prefer a tool such as Thermograf to other sophisticated multimedia material that they are also using. The latter is in concordance with other similar evaluations[16].

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