# AC 2007-2789: A SURVEY ON THE USE OF PRINTED VS. ELECTRONIC VAPOR TABLES

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# A Survey on the Use of Printed vs. Electronic Vapor Tables


## Abstract

One of the key features of thermodynamics books continues to be steam and refrigerant tables normally included as an appendix. Learning to use the steam tables has traditionally been an important component of success in entry level thermodynamics. Numerous alternatives have become available over the years and this study is an assessment of the continuing need for students to learn and use printed steam tables.

Vapor tables are currently available in a web format and as stand alone programs for PCs and handheld devices such as the Palm Pilot. The number of vapor tables available in electronic format forces engineering professors to look at the usefulness of teaching students to use the printed tables. A substantial number of faculty still feel that learning to use the printed tables teaches a useful skill and continue to use it before or instead of electronic tables. A growing number of faculties have opted to use the time savings from using the tables for other aspects of the course.

This paper is a survey of faculty, students, and engineers in related fields on how useful it is to teach students to use printed steam tables. Also included in the paper is a summary of the most popular delivery formats and programs.


## Introduction

The ubiquity of personal computers have in engineering education has brought new tools into the process. These tools simplify calculations that used to be extremely time consuming. Vapor tables are one area where students spend a lot of time and are most anxious to reduce their effort. Should students continue to be taught using tables, should we migrate to using software tools, or should both methods be taught?

Mechanical engineering students generally take their introductory thermodynamics course at some point in their first two years. A lot of new terminology and concepts are introduced in the first half of the course, making it a significant hurdle for students. [1]

There is no explicit mention of this issue in the ABET criterion for mechanical engineering programs. Thermodynamics are only mentioned in program criterion 1 on curriculum, "…the ability to work professionally in both thermal and mechanical systems areas including the design and realization of such systems".[2]

A more direct impact on the use of tables comes from The National Council of Examiners for Engineering and Surveying (NCEES). The vast majority of mechanical engineering programs in the U.S. require or recommend that students take the Fundamentals of Engineering (FE) exam before graduation. Examinees must be able to determine vapor properties using the printed tables supplied. Computers and PDAs capable of running software are not allowed in the exam. This is consistent with situation at many schools where students do not have access to a PC during tests.

**Survey Findings**

The original plan for this research was to determine the policy or standard practice at a number of schools. It became readily apparent that few schools actually have a standard, written or otherwise, about teaching thermodynamics using tables or software. The decision on how to teach vapor properties is up to the individual instructor in most cases. Furthermore, it was found that there is rarely a consensus within the department. Opinions ranged from making students use tables only to using software and covering tables just enough so students can pass the FE examination.

Of the twenty-five mechanical engineering departments surveyed, only six have an explicit policy. In four cases, students use tables only during their first thermodynamics course and are introduced to software tools in subsequent courses. In the other cases, the course syllabus suggests the use of software to check homework and work projects. Of the remaining schools, professors in six make no explicit mention or suggestions about software, leaving students to use the tables supplied in the textbook. The remaining schools are split with at least one professor leaving students to use tables exclusively and at least one suggesting at least some use of software.

Faculty members listed a number of different reasons for their strategy and a few common themes did come through. The most common reasons for teaching students to use the tables only are:

1. they will need to use them for the FE exam anyway,
2. students do not have PCs during test, so they will need to use tables at all tests,
3. it improves student comprehension by forcing them to determine which table applies to the current phase, and
4. the required steps reinforce the concept of quality for saturated mixtures.

No one used the reason “we’ve always done it that way”, but some resistance to change is expected. The common frequently cited reasons for starting with software to teach vapor properties are:

1. It reduces the time required to find properties leaving more time for more or deeper problems,
2. the program gives instant display of where the data point falls in the phase diagram (true of some packages),
3. it reduces the tedium early in the course, keeping fatigue from killing interest,
4. there is time to play with “what if” scenarios for vapor cycles,
5. it allows students to do more comparisons and iterations in design projects, and

6. the software has more refrigerants than the textbook (true of some packages).

Five professional engineers in the field were also asked for their opinions. Two of them were consultants in the power generation industry, the others work in refrigeration. All use software for vapor properties in practice. The opinion of all of them is that students should use whatever method works best for their comprehension.

One item missing in these discussions is a direct comparison of the different strategies measured against course outcomes. A designed experiment comparing these teaching methods with normal outcomes for engineering thermodynamics is needed. Specifically, is the understanding and ability to determine vapor properties and the understanding and analysis of vapor cycles influenced by the method used in instruction? If both are taught, which should be covered first? There will always be some students that will learn about and use some of the software tools whether or not it is taught in the course. Any study will have to account for this factor in the analysis.

**Survey of Software Tools**

Current software tools have made it very easy to program the vapor tables for easy access. Dr. Somerton at Michigan State University created JAVA applets to do the calculations[3]. In another application, Dr. McClain of University of Alabama – Birmingham created functions that can be accessed within MathCAD.

In most cases, departments will want to use an existing package. Following are descriptions of some of the more common tools available for accessing vapor properties. Not all handle a comprehensive list of fluids. Included in table 1 is the cost for a single seat student edition. Some have optional site licenses. All packages allow calculations in SI or IP units.

**Table 1 - Common Vapor Property Tools**

| Name | Vendor | Fluids | Platform |
|---|---|---|---|
| GP Calcs | General Physics | Water | PC |
| CATT | | | |
| Process Ace Steam Properties | Process Ace | Water | PDA (Palm OS) |
| TEST | Entropysoft | Water, several refrigerants | Internet or PC |
| ESS | McGraw-Hill | Water, several refrigerants | PC |
| NIST12 | NIST | Water, several refrigerants | Internet |

* price is for a single student version

## GP Calcs™

GP Calcs ™ is a product of General Physics Corporation, http://www.gpworldwide.com/gpcalcs. GP Steam is a part of the product that was developed for power generation utilities and has data for water only. It has a table-style format (figure 1), allowing users to input any two properties and calculates the rest.

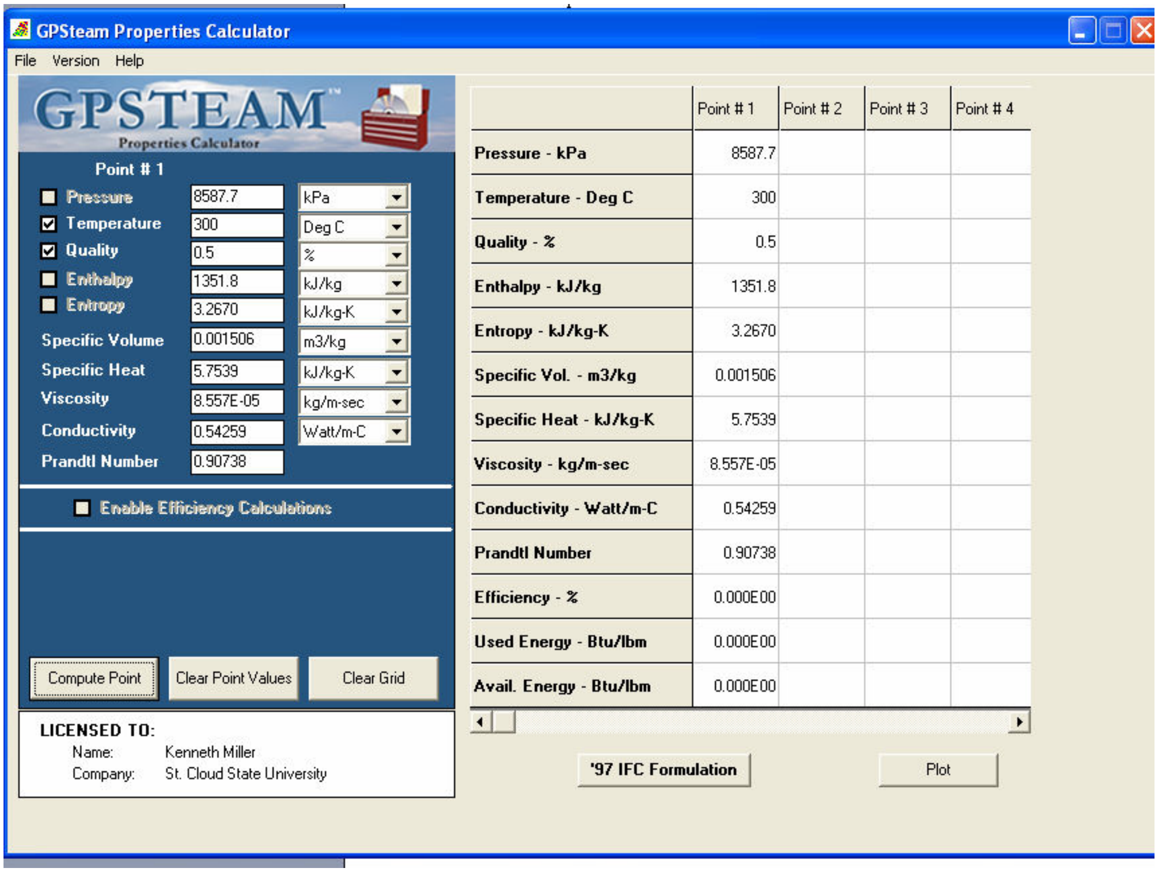


**Figure 1 - GP Steam Interface**

Output for a several calculations can be saved as separate points, which can then be pasted to a spreadsheet or text document. Also part of the package is an add-in for Microsoft Excel that allows the conversions to be made in the form of spreadsheet functions. An example is the function GPSTQH which returns enthalpy given temperature and quality as arguments.

The packaged used is the student version of a more elaborate tool for power plant design and operation. Some of the other useful items included are; a gas properties calculator, data and heating values for coal from various sources, heating oil, and natural gas, and a psychrometric calculator.

The student edition comes on a CD that must be loaded using a supplied key. There is not site license option for the student version. The currently distributed CD is version 5.0.

**Process Ace Steam Properties**

Process Ace Steam Properties is a product of Process Ace Software, http://www.processacesoftware.com/. The program runs on PDAs using Palm OS®. Users can input any two properties and the remaining properties will be displayed. This program was used as a part of the 21st Century Thermodynamics course described by Balmer[2].

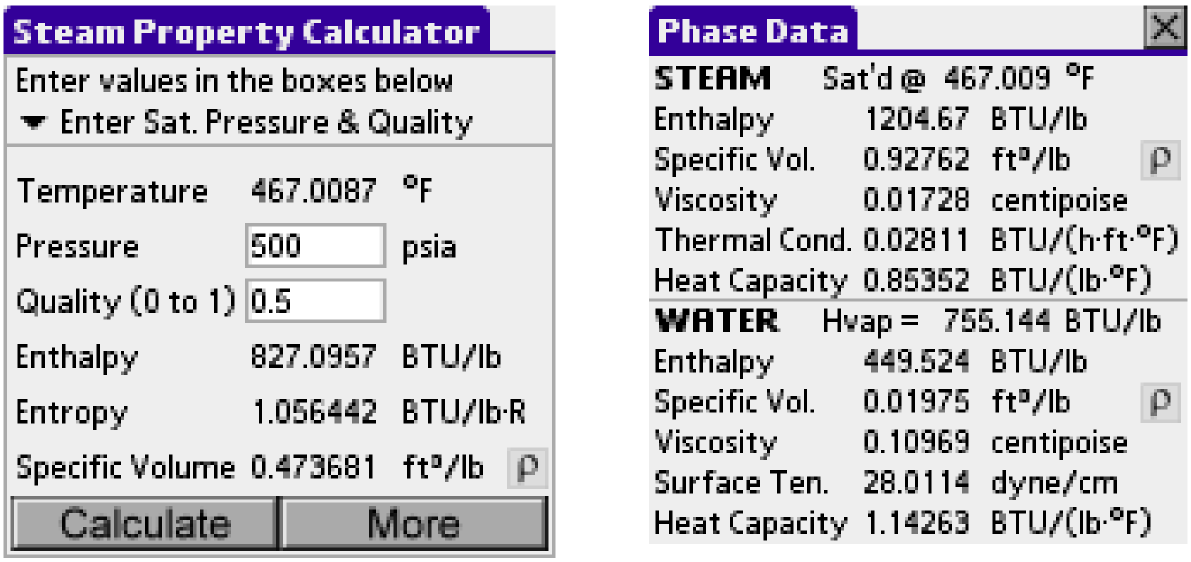


**Figure 2 - Process ACE interface**

The interface is shown in figure 2. The setup menu allows selection of units, then the pull down menu on top of the first screen is used to select the input terms. The **Calculate** button gives the properties shown on the left. Selecting **More** gives the data screen on the right. For all the specific volume values, there is a ρ button to convert it to density.

The current version is 2.2.0.

**The Expert System for Thermodynamics (TEST)**

The Expert System for Thermodynamics was created by Subrata Bhattacharjeeof San Diego State University, http://www.thermofluids.net/. This package can be run locally or over the web. The most common component for finding vapor properties is the calculator interface, shown in figure 3.

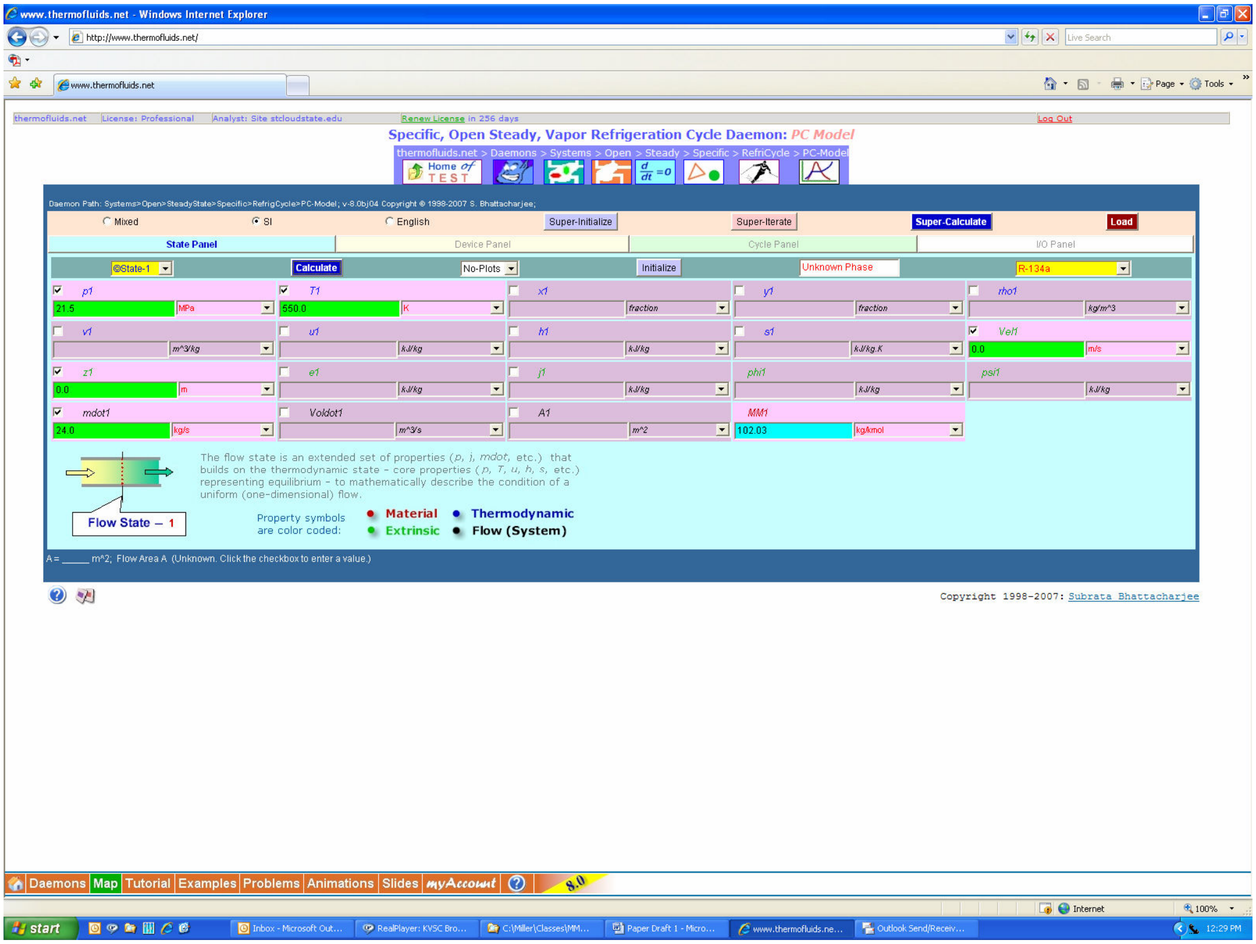


**Figure 3 - TEST Calculator Interface**

The program allows calculation for a number of steps, linking properties between them. For example step 3 can use the entropy of step 2. Simple calculations in the format of Excel equations can also be done in the cells. Calculations can be saved to a text file, as shown in figure 4. This example shows how ideal and actual turbine output states can be calculated.

#-------------------RESULT OF SUPER-CALCULATION---------------------
#*******Analyst: Site stcloudstate.edu; TEST Mode: Professional*******
#
##########################################################################################
# Copy (select text by dragging the mouse & pressing Ctrl_c) and paste (Ctrl_v) the following TEST-code onto a file
# to save for later use. To reproduce the visual solution in a new session launch the appropriate daemon,
# identified by the full daemon path listed below. Paste (Ctrl_v) the saved TEST-Code on this I/O Panel,

```
#  click Load and then Super-Calculate to recover the solution. You can email a solution in this manner.
##########################################################################################
#
# Daemon Path: Test>Daemons>Systems>Open>SteadyState>Specific>RefrigCycle>PC-Model; Version: v-8.0bj04
#
#--------------------Start of TEST-Codes---------------------------------------------------------------------------
  States   {
           State-1:  H2O;
           Given:      { p1= 12.5 MPa;   T1= 550 deg-C;   Vel1= 0.0 m/s;   z1= 0.0 m;   mdot1= 24.0 kg/s;   }\
           State-2:  H2O;
           Given:      { p2= 20.0 kPa;   s2= "s1" kJ/kg.K;   Vel2= 0.0 m/s;   z2= 0.0 m;   mdot2= "mdot1" kg/s;   }
           State-3:  H2O;
           Given:      { p3= "p2" kPa;   h3= "h1-0.85*(h1-h2)" kJ/kg;   Vel3= 0.0 m/s;   z3= 0.0 m;   mdot3= "mdot1"
kg/s;   }
           }
#----------------------End of TEST-Codes-------------------------------------------------------------------------------
#
#  Solution Time: Jan 17, 2007 12:37:38 PM; Analyst: Site stcloudstate.edu
#  Daemon Path: Daemon Path: Systems>Open>SteadyState>Specific>RefrigCycle>PC-Model; v-8.0bj04
#
#*********************Detailed
Output**************************************************************************************
#
#  States
#
#          State-1:  H2O > Superheated Vapor;
#                    Given:      p1= 12.5 MPa;   T1= 550 deg-C;   Vel1= 0.0 m/s;
#                             z1= 0.0 m;   mdot1= 24.0 kg/s;
#                    Calculated:   rho1= 35.70215 kg/m^3;   v1= 0.02801 m^3/kg;   u1= 3124.98413 kJ/kg;
#                             h1= 3475.10303 kJ/kg;   s1= 6.62887 kJ/kg.K;   e1= 3124.98413 kJ/kg;
#                             j1= 3475.10303 kJ/kg;   Voldot1= 0.67223 m^3/s;   A1= 67222.84108 m^2;
#                             MM1= 18.0 kg/kmol;
#
#          State-2:  H2O > Saturated Mixture;
#                    Given:      p2= 20.0 kPa;   s2= "s1" kJ/kg.K;   Vel2= 0.0 m/s;
#                             z2= 0.0 m;   mdot2= "mdot1" kg/s;
#                    Calculated:   T2= 333.21198 K;   x2= 0.81916 fraction;   y2= 0.99997 fraction;
#                             rho2= 0.15954 kg/m^3;   v2= 6.26806 m^3/kg;   u2= 2057.90039 kJ/kg;
#                             h2= 2183.22412 kJ/kg;   e2= 2057.90039 kJ/kg;   j2= 2183.22412 kJ/kg;
#                             Voldot2= 150.43349 m^3/s;   A2= 1.504334907532E7 m^2;   MM2= 18.0 kg/kmol;
#
#
#          State-3:  H2O > Saturated Mixture;
#                    Given:      p3= "p2" kPa;   h3= "h1-0.85*(h1-h2)" kJ/kg;   Vel3= 0.0 m/s;
#                             z3= 0.0 m;   mdot3= "mdot1" kg/s;
#                    Calculated:   T3= 333.21198 K;   x3= 0.90133 fraction;   y3= 0.99999 fraction;
#                             rho3= 0.145 kg/m^3;   v3= 6.89671 m^3/kg;   u3= 2239.11279 kJ/kg;
#                             s3= 7.21035 kJ/kg.K;   e3= 2239.11279 kJ/kg;   j3= 2377.00596 kJ/kg;
#                             Voldot3= 165.52096 m^3/s;   A3= 1.655209579468E7 m^2;   MM3= 18.0 kg/kmol;
#
#
#--------------Spreadsheet Friendly Property Table (tab-delimited, 999999 signifies unknown value)---------------------
#
#State    p(kPa)    T(K)       x          v(m3/kg)          u(kJ/kg) h(kJ/kg) s(kJ/kg)
#  1      12500.0              823.2                               0.028            3124.98           3475.1
          6.629
```

| | | | | | | |
|---|---|---|---|---|---|---|
| # 2 | 20.0<br>6.629 | 333.2 | 0.8 | 6.2681 | 2057.9 | 2183.22 |
| # 3 | 20.0<br>7.21 | 333.2 | 0.9 | 6.8967 | 2239.11 | 2377.01 |

# ******************************

**Figure 4 - Sample TEST Calculation**

This tool has several features that can be used to help with teaching. It has a large number of fluids and gases available, including more than 15 refrigerants. There are several animations available showing common gas and vapor cycles. When calculating a number of steps as shown above, it can also plot them using most combinations of p, v, T, s, and h axis. Another feature is the ability to bring kinetic and potential energy into the calculations.

The current version of the software is 8.0.There are several options available for purchase, including a site license, student edition, local (CD). A free evaluation period is available to students. Instructors can get a free copy for use on campus.

## Engineering Equation Solver (EES)

Like TEST, the Engineering Equation Solver (EES) was written by college professors for help in teaching thermodynamics. TEST was created by William A. Beckman and Sanford A. Klein. A limited student version is supplied by McGraw-Hill with several of their textbooks, http://www.fchart.com/.

The functions for thermodynamics are similar to TEST, allowing users to define various state properties and calculate the remaining states. It also handles a similar collection of fluids. Calculations are defined through text windows using equations combining constants, values from other states, and functions for properties. There are also commands to plot phases and diagram systems.

This software comes with several textbooks from McGraw-Hill. Version 7.692D. There are four versions available, including limited and standard academic versions available without cost for departments using Mc-Graw-Hill textbooks. Commercial and Professional versions are also available.

## NIST12

NIST 12 is an academic version of the NIST Standard Reference Database 23[5]. It is supplied with the Thermodynamics textbook from Cambridge University Press, http://www.cambridge.org/.

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The program is a lookup style interface with properties for water, five refrigerants, and ten gasses. This program has the largest number of properties available for the software reviewed here. Figure 5 shows the property selection interface.. Output can be provided for individual points or in the form of tables and graphs, as shown in figures 6 and 7.

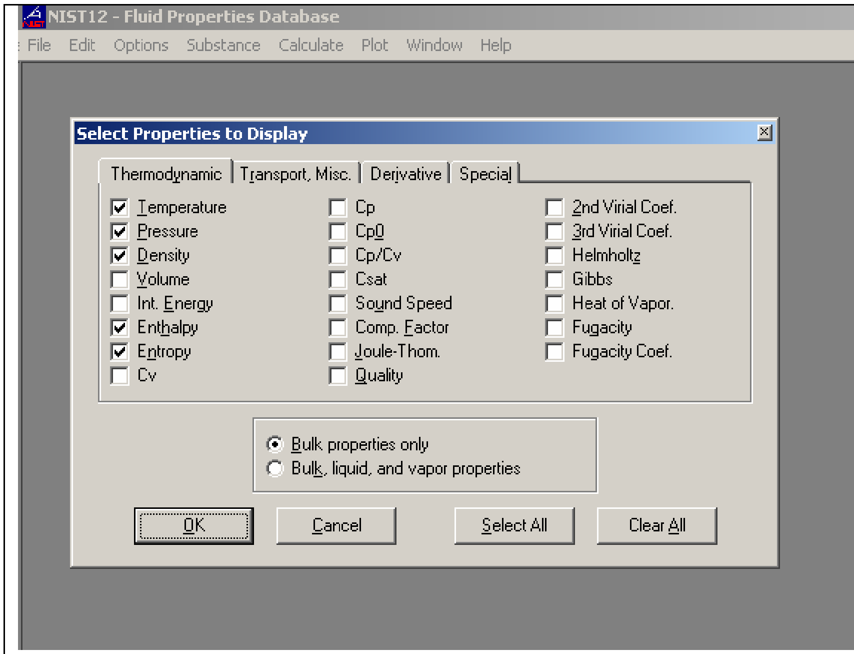
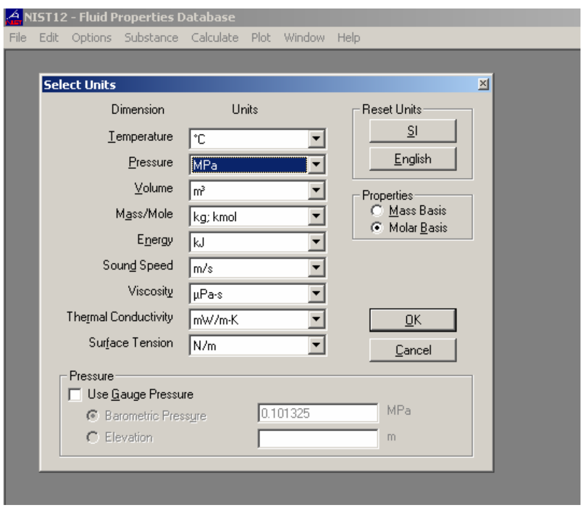



**Figure 5 - NIST12 Property Selection**



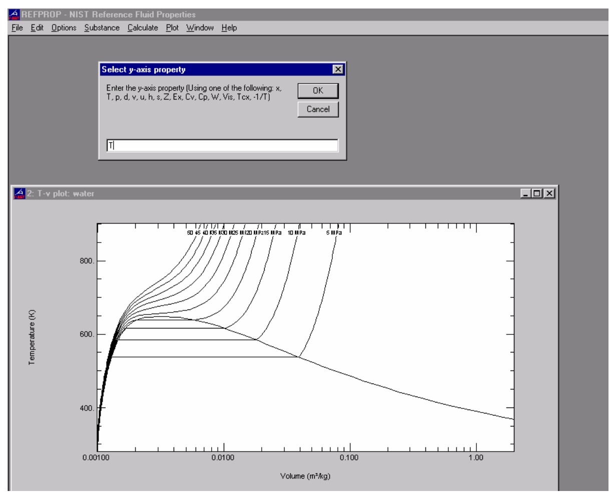




**Figure 7 - Sample NIST12 Plot**

**Figure 6 - NIST12 Unit selection**

One related link available at NIST is http://webbook.nist.gov/chemistry/fluid/ . This is a simplified calculator for find point properties for a large number of fluids.

The author has copies of the first three packages and uses GPCalcs® and TEST in teaching thermodynamics and a related thermal sciences laboratory course. One of the primary advantages in these two programs (and EES) is the ease of creating a cycle using the relationships between various states, then quickly finding the effect of changing a parameter. One recent case was calculating the COP for a heat pump. Once a group made their calculations, they looked at the effect of 6 different refrigerants on the same conditions. It is unlikely that this group of students would have done this comparison if it required using six sets of tables.

## Conclusions

Introductory courses in thermodynamics will need to continue teaching the use of printed vapor tables as long as it is need for the Fundamentals of Engineering Exam. The need still exists for a study of the effects these tools have on comprehension, including how and when to introduce them. The tools offer a number of significant advantages, particularly when covering vapor cycles and working design projects.

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