

AC 2007-1912: SOFTLAB VIRTUAL LABORATORY ENVIRONMENT. THERMODYNAMICS EXAMPLES

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SoftLab Virtual Laboratory Environment

Thermodynamics Examples

Abstract

An outstanding way for students to learn scientific and engineering subjects and to experience the joy of discovery is through hands-on laboratory experience including self-directed creative experimentation. Creating such an environment is impractical for most educational institutions. Virtual laboratories, while lacking some of the benefits of real ones, offer advantages of their own. These include, among others, low cost and ready availability. Such a laboratory, called **SoftLab**, is described here as implemented for introductory thermodynamics.

Introduction

Educators generally recognize that students learn better by hands-on self-discovery than by just being lectured to. Every school in the world at every level of education would like to be able to provide excellent laboratory facilities. And wouldn't it be wonderful if each student could access these facilities whenever he wanted to so he could do small experiments to clarify ideas from class and textbooks or for pursuing his own ideas? Several years ago G.R. was able to interview all forty of the Stevens Scholars, freshmen students believed to be especially highly qualified for a technical education. One thing each one of them wanted was just this kind of laboratory opportunity.

A number of factors render this impractical for widespread use, including among other things, cost of equipment, space required, safety considerations, and need to provide access to the laboratory for many hours each day. Even further from realization would be to make such facilities available to each individual student to use when and where he or she chooses. A highly flexible, virtual, computer based laboratory can obviate these problems and provide an excellent learning environment. Virtual lacks much of the impact of real, but can provide unique advantages, such as availability on demand, and insignificant cost.

SoftLab is such a flexible laboratory environment. Its goal is to simulate a laboratory space having a well-equipped storeroom of instruments and a variety of materials. Using SoftLab a student may be guided by an instructor to perform an experiment, or the student might also conceive of one on his own. The student may choose a substance to study, take out the instruments he needs, connect them together, make his measurements, and record and plot his results. The computer screen is the laboratory room. The experimental possibilities open to the student certainly are limited by the ability of the developers to maximize flexibility in a practicable way. Algorithms implemented so far have achieved the desired flexibility, and SoftLab has been well received.

The implementation of SoftLab was begun first for introductory thermodynamics, a one semester course one of the authors taught for many years to all sophomore engineering students, about 250 per year. SoftLab presently has the virtual instruments for broadly studying the first law of thermodynamics in real water and in ideal gases in closed systems and for exploring the

thermodynamics of phases and phase transitions. Further developments to meet the needs of a full engineering thermodynamics course have been designed but not yet implemented.

What SoftLab is Today

The next few pages present a description of the present state of SoftLab and illustrate its potential for student discovery. The following figure shows the current SoftLab laboratory space and an experimental setup to observe the temperature of water as it is heated in a calorimeter from ice at low temperatures to liquid to vapor at high temperatures. A mercury thermometer is included as well as digital instruments for measuring time, temperature, heater voltage and mass of water in the liquid state. When the experiment is running the student sees the readings of the instruments changing and the liquid rising in the thermometer.

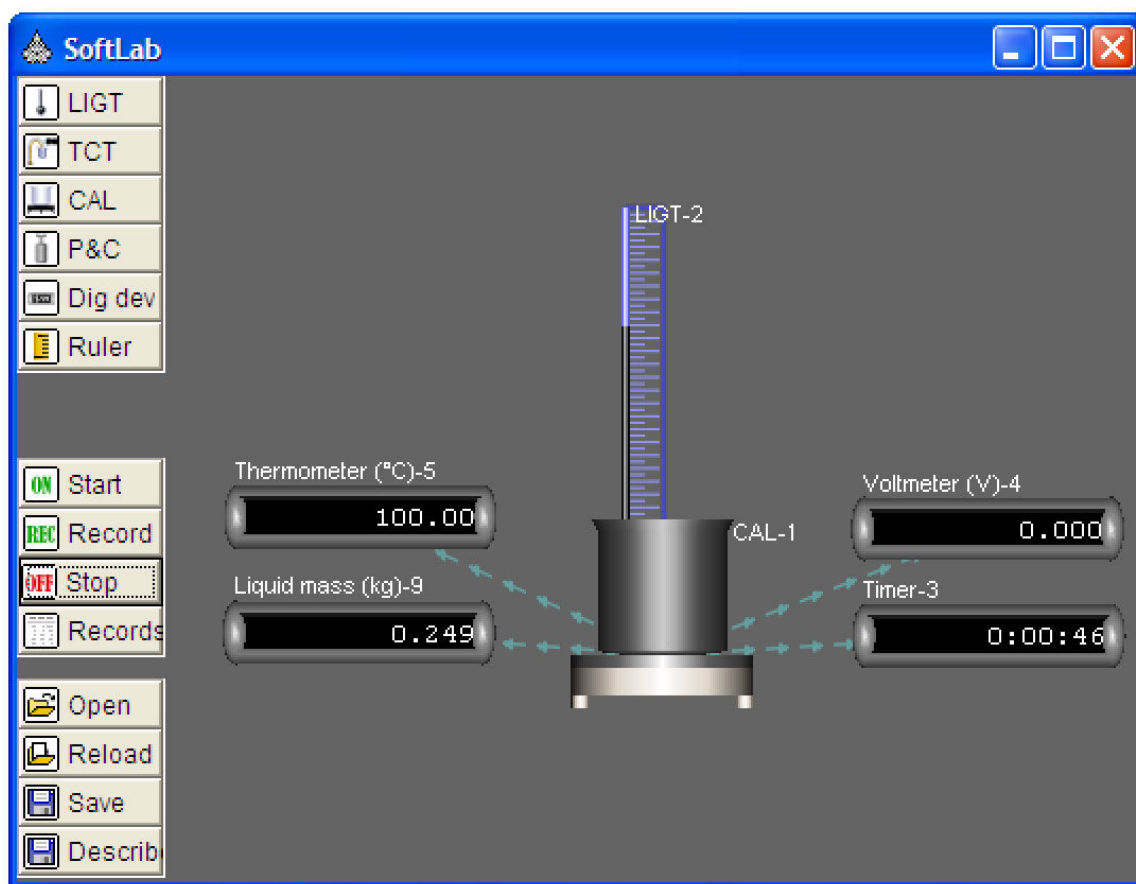


Figure 1. Softlab setup to measure temperature of water as heated.

The buttons on the left side call up a variety of instruments, which the student connects as he wishes, and provide for other substances besides water. More instruments and substances will be added as development continues. The experimental setup can be saved for recreating the experiment. Data can be recorded for analysis and graphing of results. Everything shown in the experimental space in this figure was selected from the storeroom and arranged in space at will just as would be done by a student. Additionally, key parameters of the liquid-in-glass

thermometer itself may be selected by the student, including the nature of the liquid, if the student chooses to design a thermometer specifically for the intended use. To create this setup the student must decide the purpose of the experiment, what instruments are needed, what data should be recorded and how to analyze and present the results. Students must learn to do these things. SoftLab is an efficient tool for teaching these skills.

Some results from this experiment are shown in the next figure. Here temperature of the water is plotted versus time of heating. The horizontal portions are where the water is changing phase from solid to liquid and later liquid to vapor. In lecture, students were presented with this experiment as an introduction to phases, phase changes, and the use of the temperature arrests to calibrate thermometers. From this plot one can derive the heat capacities of solid, liquid and vapor as well as the latent heats of melting and evaporation. Water is modeled accurately enough in SoftLab to yield realistic numerical results. Ideal gases are also included, and other real substances important in engineering, such as refrigerants, will be added.

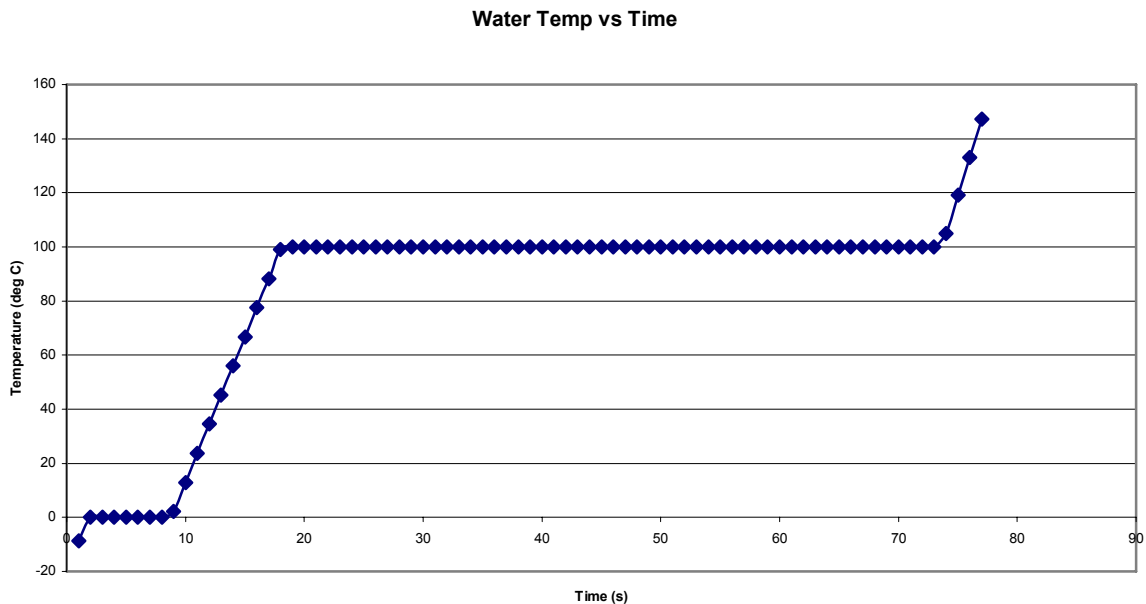


Figure 2. Temperature versus time on heating water from ice to vapor phases.

The next figure shows a remarkable phenomenon that very few people ever observe for themselves, but which is easy in SoftLab.

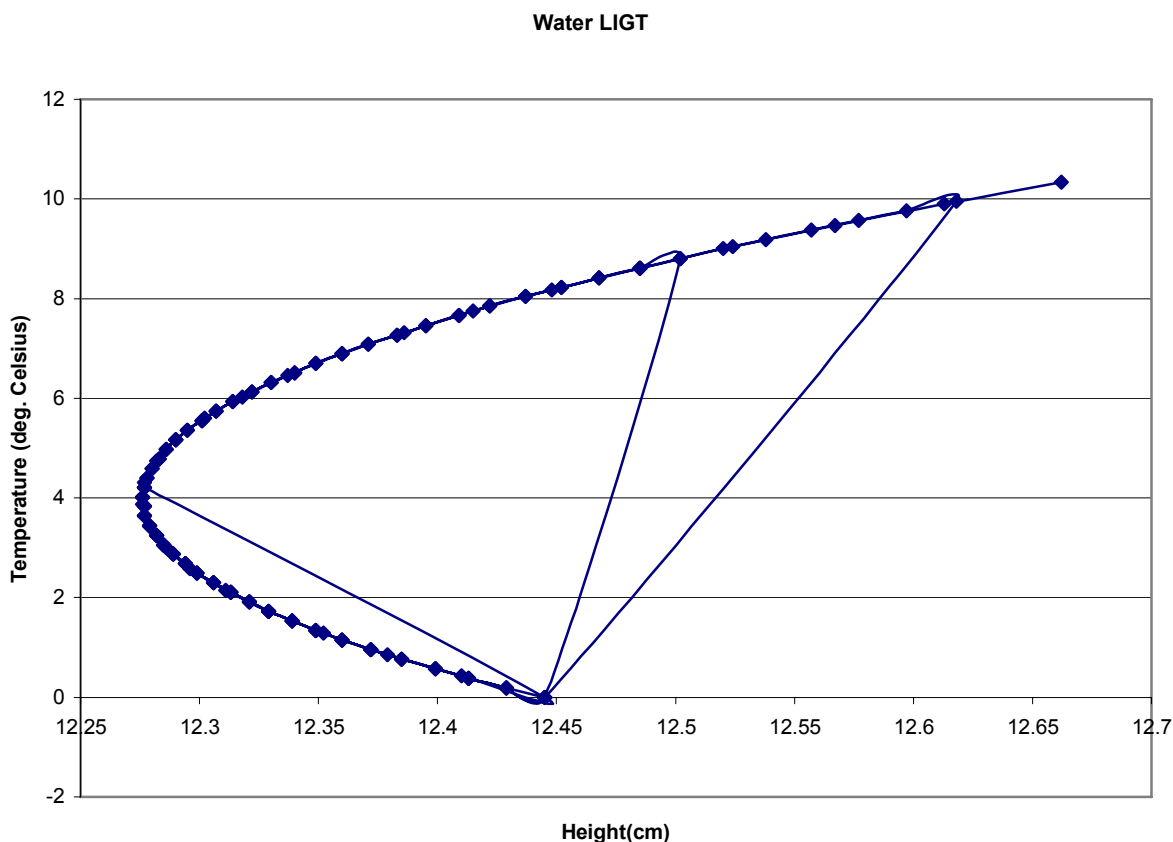


Figure 3. Linear expansion of water near 4 °C. T(°C) versus column length (cm).

On the vertical scale this figure shows the temperature of liquid water as it is heated from the freezing point to about 10 °C. The horizontal axis gives the height of the liquid in a water-in-glass thermometer. As the temperature rises the height of the water level actually drops! This is completely different from almost every other liquid in nature. One can even make a case that this behavior is responsible for life as we know it surviving on Earth through the ice ages. Above 4 °C the water expands just like every other liquid. When people see this experiment in action their faces light up with excitement.

As a final example, the last figure shows the result of squeezing water in a piston-cylinder device while keeping the temperature constant. The piston-cylinder is one of the instruments in SoftLab and is used to study properties of matter in which temperature, volume, pressure and mass may be varied. In this figure pressure is plotted versus specific volume of the water in the cylinder held at 548 K. The horizontal portion arises as the vapor --- at large volume --- begins to condense into liquid. The sharp rise in pressure at low volume is because here the water is entirely liquid, and liquids are practically incompressible. This experiment gives the water phase diagram and that of pure substances generally, much more reality and meaning than figures in a textbook.

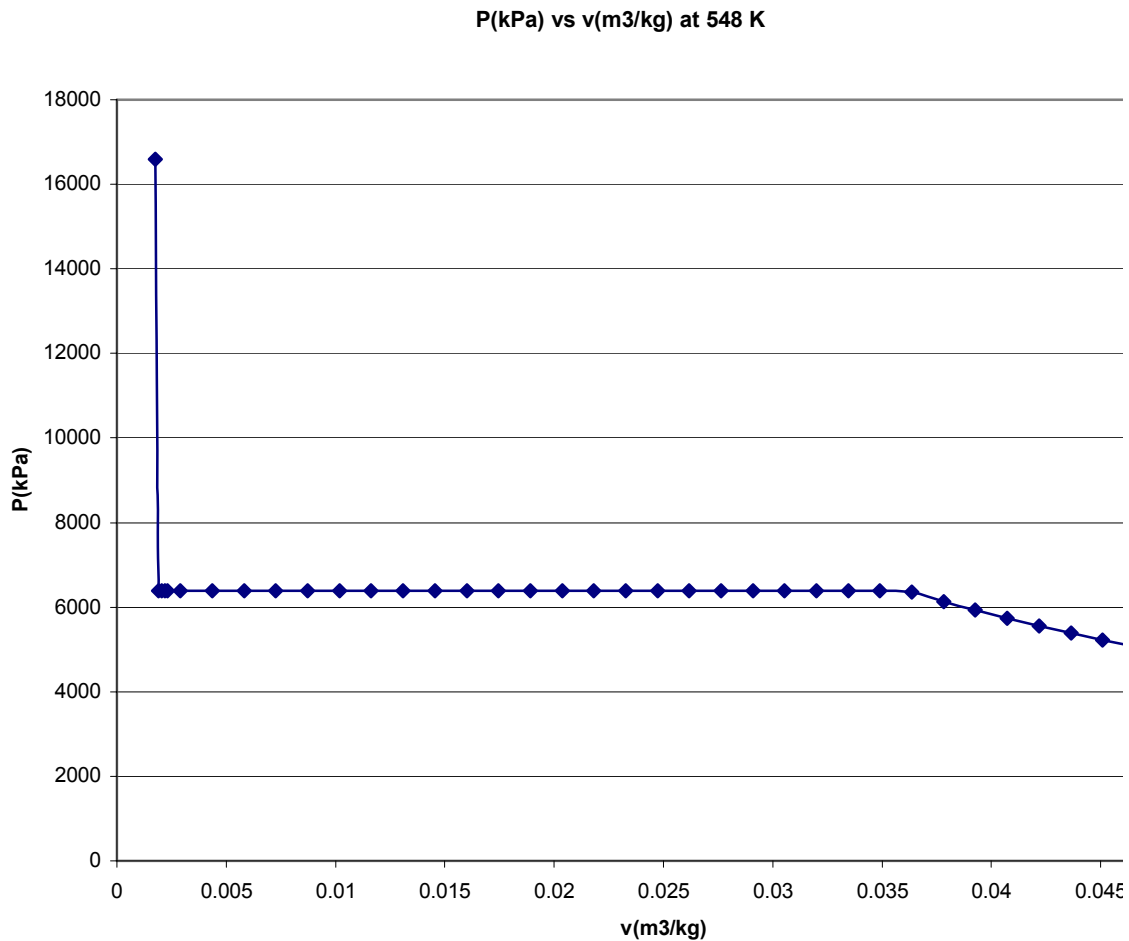


Figure 4. Pressure P(kPa) versus specific volume v(m³/kg) of water at 548 K.

Discussion

The SoftLab software was written by P.B. using the Elica¹ programming language, which he created. Besides his expertise in this language, other reasons for using Elica include:

1. Elica has a good set of ready-to-use graphical libraries. Mainstream languages like C, Java, etc. come only with some low-level graphical capabilities. The side effect is that Elica requires less time to implement virtual models.

2. Elica has a dynamic support. This means that when there is need to change Elica to provide new functionality for the SoftLab project it is possible to make this change. And several times Elica was changed to accommodate it to SoftLab. The developers of other languages will never make such changes in their implementations unless this change will be beneficial for a large number of users.

3. Elica is free.

SoftLab is not yet ready for distribution. Its functionality must be enhanced to enable experiments involving the second law and also open systems. Algorithms permitting these developments have been devised but not implemented. Eventually user manuals must also be prepared.

1. <http://www.elica.net/site/index.html>