Instructional Courseware Developed for Thermodynamics Course

Yucheng Liu

Department of Mechanical Engineering
University of Louisiana at Lafayette

Abstract

This paper presents concise computer courseware for solving three types of fundamental thermodynamic problems: determine gas status after specified processes; evaluate pure substance's thermodynamic properties at a given state; analyze basic thermodynamic cycles, including power cycle, refrigeration cycle, and heat pump cycle. Common programming language C# is selected to develop the courseware and interfaces. The application of the developed courseware in teaching thermodynamic courses can efficiently help students to improve their problem-solving skills and make them better understand basic thermodynamic laws. The presented teaching approach can be expansively applied in thermodynamics education.

Keywords: thermodynamics, courseware, C#, education.

Introduction

A major objective of a thermodynamic course is to develop students' capability in solving engineering problems that involve thermodynamic principles. However, it is a common phenomenon that most students have trouble in solving thermodynamic problems: some of them cannot properly build an image of the problem and do not know how to start; some of them are not familiar with fundamental thermodynamic principles and generally used problem-solving techniques therefore they struggle everywhere when solve the problem; even worse, without thinking carefully ahead, some students hastily start the problem in the middle by selecting some seemingly appropriate equation, substituting in numbers, and quickly calculating a result. Such common pitfalls associated with problem solving can result in difficulties as problems become more complicated.

In order to efficiently guide the students in solving such thermodynamic problems and improve their problem-solving capability, an instructional computer program is a useful tool. Development and application of instructional programs have been widely employed in engineering education. Canakci [1] developed a program called Pile-D using Microsoft Excel for the teaching of pile foundation design to geotechnical engineering students. Kahn-Jetter and Sasser [2] presented software that used spreadsheets to analyze advanced machine design problems involving optimization concepts. Sieres and Fernandez-Seara [3] designed a courseware for simulating vapor compression refrigeration systems that are self designed by the user. Rivas et al [4] used Microsoft spreadsheet Excel to develop a program that can define, analyze and optimize models of systems and processes of medium complexity.

Based on the above literature, this study develops courseware using C#, which can help and guide students in solving three types of thermodynamic problems: determine gas status after specified processes; evaluate thermodynamic properties at a given state; and analyze power, refrigeration and heat pump cycles. Friendly user interfaces are designed for a user to input given data and information and for providing useful hints for the step-by-step approach. Mathematical models and algorithms of these problems have been implemented in the C# programs.

Determine Gas Status

Determining gas status during a series of processes is a fundamental type of thermodynamic problem. Given an initial status and a series of quasi-equilibrium processes, such problems may require you to solve the gas status after each process and evaluate the work during each process. Typical quasi-equilibrium processes and their governing equations are (assume the process is from state 1 to 2):

Isothermal process:

$$T_1 = T_2,\ W = \int_1^2 p\,dV = p_1 V_1 \ln\frac{V_2}{V_1} \text{ or } W = mRT\ln\frac{V_2}{V_1} \text{ (ideal gas)} \tag{1}$$

Isobaric process:

$$P_1 = P_2,\ W = P(V_2 - V_1) \tag{2}$$

Isometric process:

$$V_1 = V_2,\ W = 0 \tag{3}$$

Polytropic process:

$$PV^n = \text{constant},\ W = \frac{p_2 V_2 - p_1 V_1}{1-n} \text{ or } W = \frac{mR(T_2 - T_1)}{1-n} \text{ (ideal gas)} \tag{4}$$

In the above equations, P denotes pressure, V denotes volume (small letter v means specific volume $v = V/m$), T denotes temperature, W denotes work, m denotes mass of the gas, and R is the gas constant. In many books, an isothermal process is also considered as a special polytropic process with $n = 1$.

The basic approach of solving such problems is to correctly identify the number and type of individual processes, and number of states of the process series; next to locate all the given conditions at the proper state or process; and finally to calculate the gas properties at unknown states using eq. (1) to (4). Based on this approach, the courseware program is developed, in which the listed mathematical models have been implemented.

Example 1

Air in a closed system undergoes three processes in series: process 1 to 2 is a polytropic compression with $n = 1.3$ from $P_1 = 180kPa$, $v_1 = 0.05m^3/kg$ to $v_2 = 0.03m^3/kg$; process 2 to 3 is an isometric process and $P_3 = P_1$.

Question: determine the unknown P and v at each state and evaluate the work per mass (kJ/kg) for each of the processes; sketch the processes on the P-v diagram.

This problem can be easily solved using the presented courseware as shown from Figs. 1 to 3.

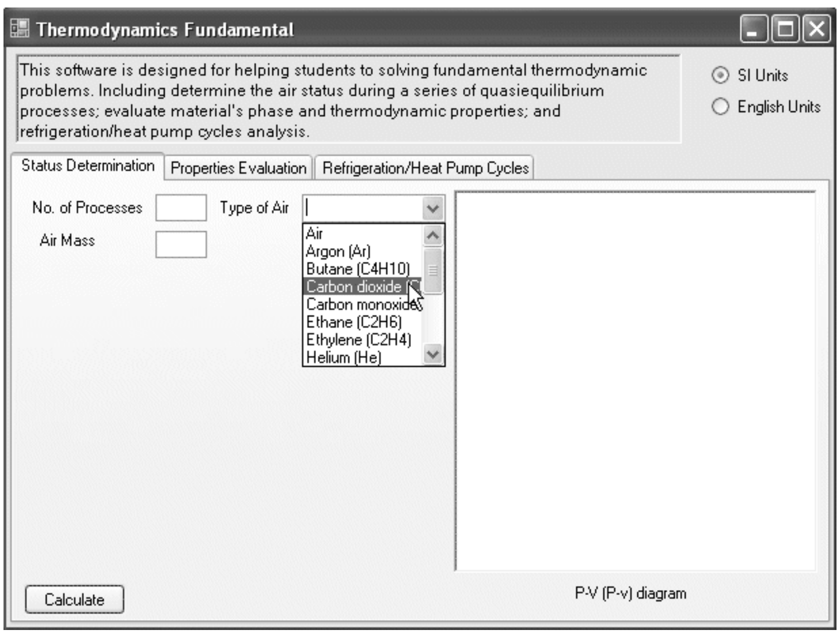

Figure 1. Main interface for determining gas status

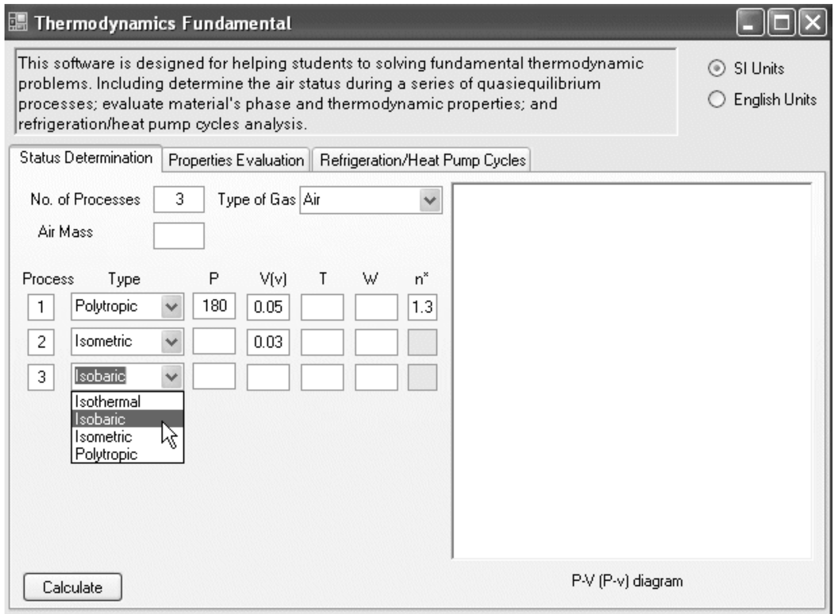

Figure 2. Input given conditions to solve problem 1

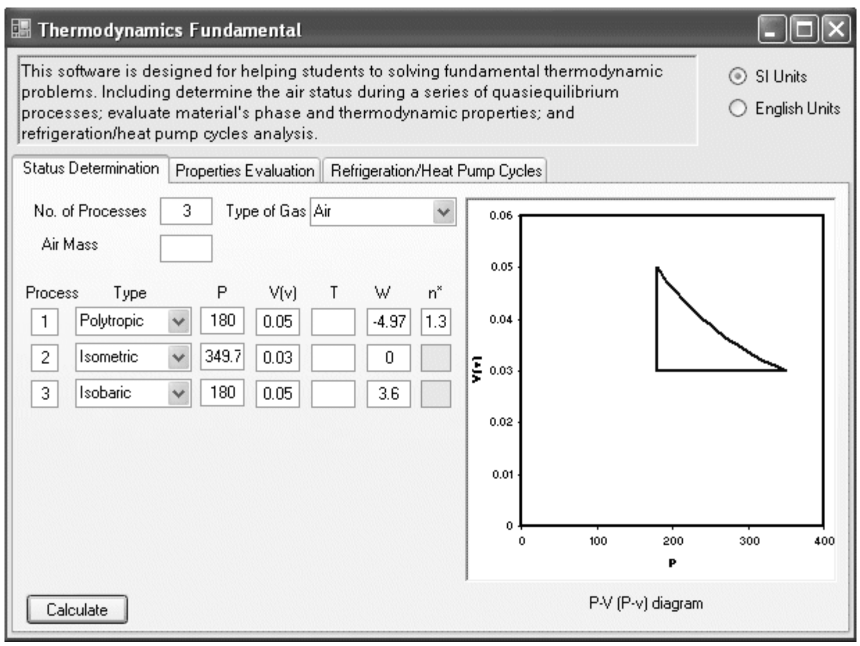

Figure 3. Calculate and display solutions of problem 1

Evaluate Substance's Properties

Evaluating thermodynamic properties of pure substances based on given conditions is an important skill in solving thermodynamic problems. Engineers usually have such problems when analyzing thermodynamic cycles and systems. Besides P, V(v), T, other important thermodynamic properties include internal energy (u), enthalpy (h), and entropy (s). The same substance may have different properties at different states: liquid, liquid-vapor mixture, and vapor state. In order to correctly identify the properties, students have to first determine the state of that pure substance at given conditions. In teaching practices, it is found that most students were confused about how to properly determine the substance's state. A systematic approach has to be created to guide the students in solving such problems.

The best way to evaluate the thermodynamic properties of a substance at a certain state is using property tables, which can be found in any thermodynamic text book. For any substance, three types of property tables are prepared in the books: saturation (liquid-vapor) temperature table – lists of properties for liquid state or liquid-vapor mixture with respect to different temperatures; saturation (liquid-vapor) pressure table – lists of properties for liquid state or liquid-vapor mixture with respect to different pressures; superheated (vapor) table – lists of properties for vapor state with respect to different temperatures. In practice, students usually have difficulties in properly locating the state of the substance on the right property table. In this section, we introduce how to use the correct property tables to determine a substance's state based on given information and retrieve any property p, where p_g denotes the property of saturated vapor and p_f denotes the property of saturated liquid. The algorithm is:

Case 1: if the substance's P and T are given

From the property table to find the saturation temperature T_{sat} at the given P, if $T > T_{sat}$, the substance is in vapor state so go to the superheated table to retrieve properties at temperature T; if $T < T_{sat}$, it is in liquid state so go to the saturation table and evaluate the property using $p \approx p_f$; if $T = T_{sat}$, it is in saturated state and more information is needed to calculate the quality x (see case 2) and fully determine the unknown properties.

Case 2: if P or T is given and another property r is given

Find r_f and r_g based on the given P or T from the saturation pressure or temperature table. If $r > r_g$, the substance is in the vapor state so go to the superheated table to retrieve other properties; if $r \approx r_f$, it is in liquid state so evaluate the unknown properties using $p \approx p_f$; if $r_f < r < r_g$, the substance is a liquid-vapor mixture and we have to determine the quality x using

$$x = (r - r_f)/(r_g - r_f) \text{ or } (r_{fg}) \tag{5}$$

Other properties then can be calculated as

$$p = (1 - x)p_f + xp_g \tag{6}$$

Here the r and p can be any properties that are listed in the property tables. In case the given P or T do not locate exactly on the grid of values provided by property tables, the property has to be evaluated using linear interpolation between two adjacent table entries [4, 5]. This approach has been embedded into the proposed courseware.

Example 2

Given: 1) water at T = 200°C and v = 0.1m^3/kg, find its phase and u; 2) water at P = 300kPa and T = 100°C, find its phase and v.

By using the courseware, question 1) was solved from Figs. 4 to 8 and question 2) can be solved as shown in Figs. 9 and 10.

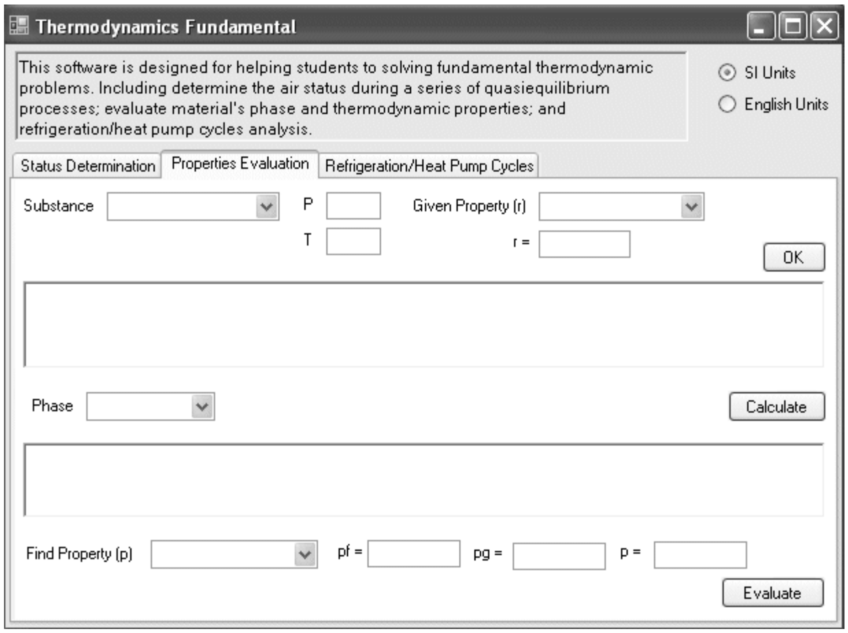

Figure 4. Main interface for evaluating substance's properties

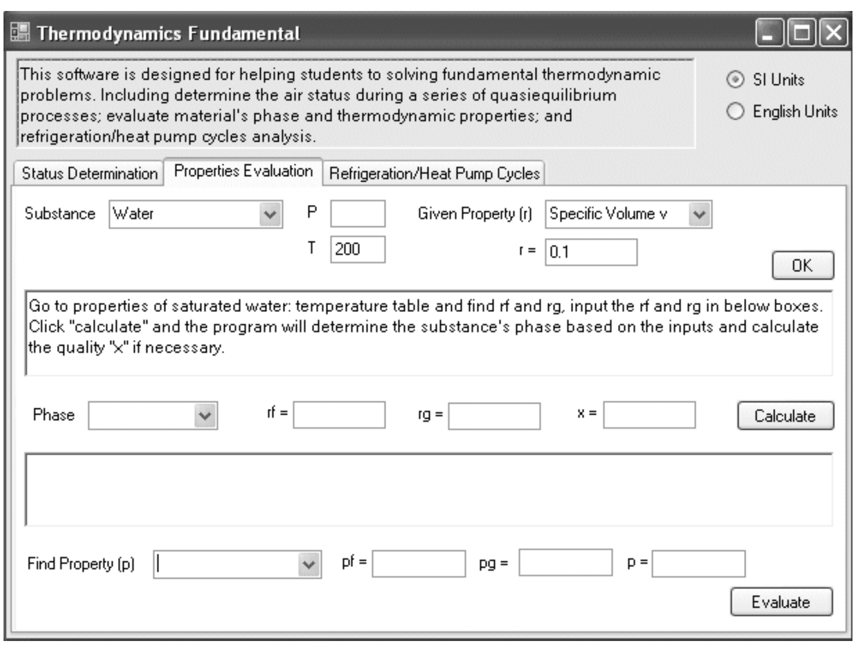

Figure 5. Solve 1) using the interface, step 1

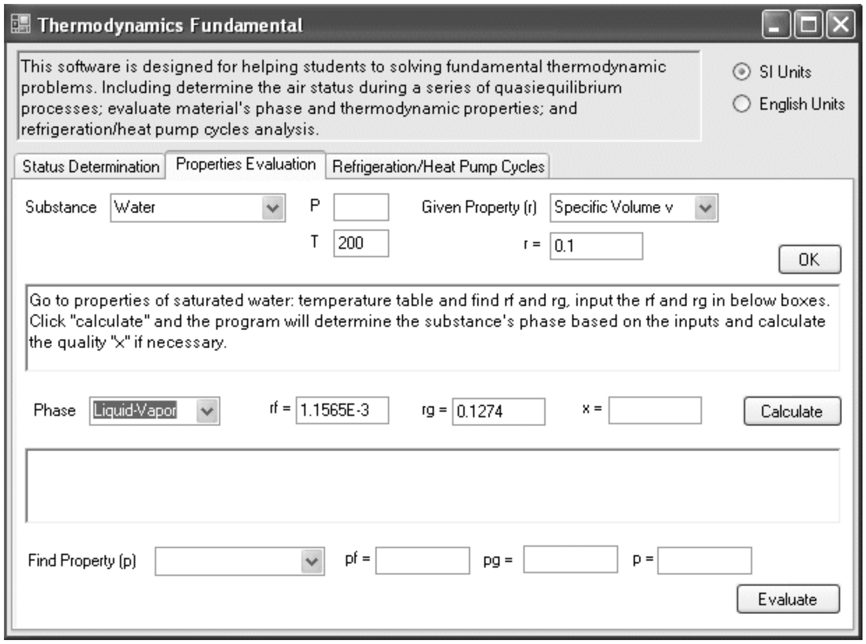

Figure 6. Solve 1) using the interface, step 2

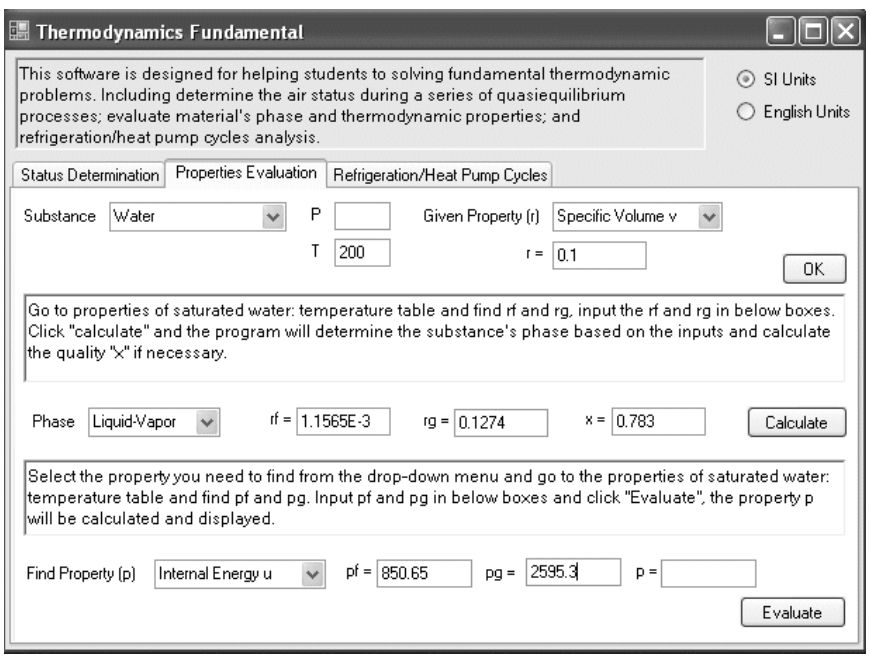

Figure 7. Solve 1) using the interface, step 3

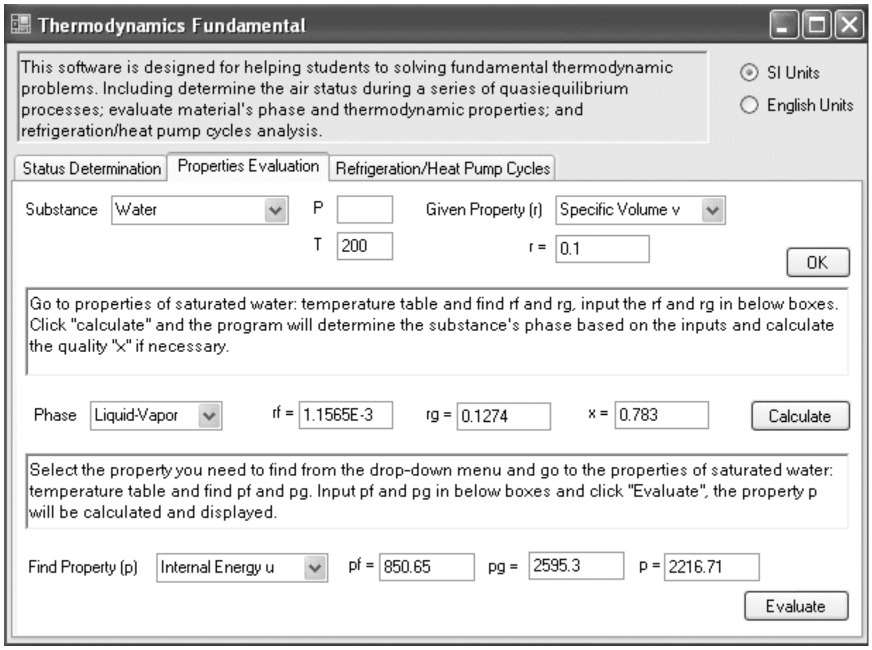

Figure 8. Find solution for 1) using the interface

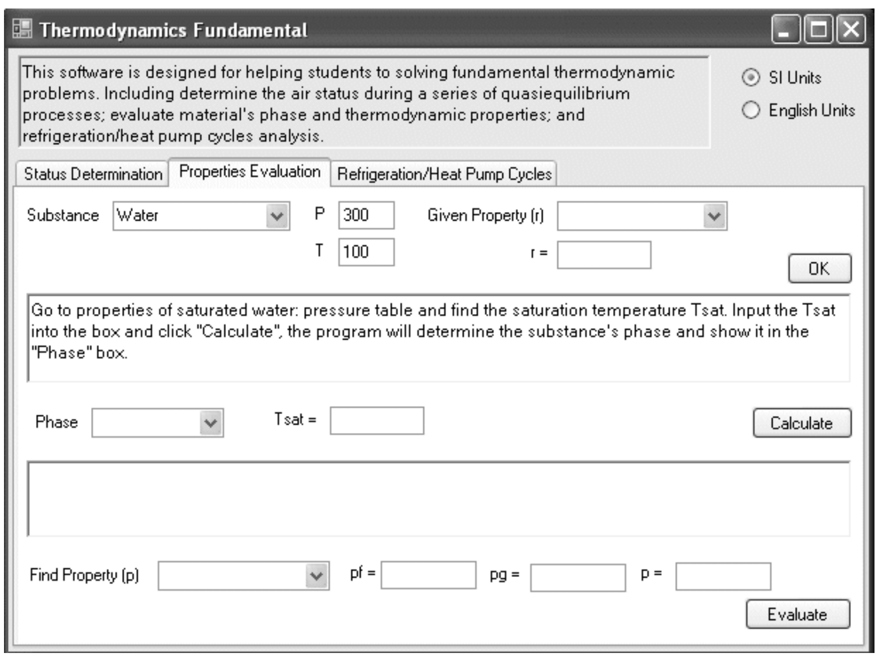

Figure 9. Solve 2) using the interface, step 1

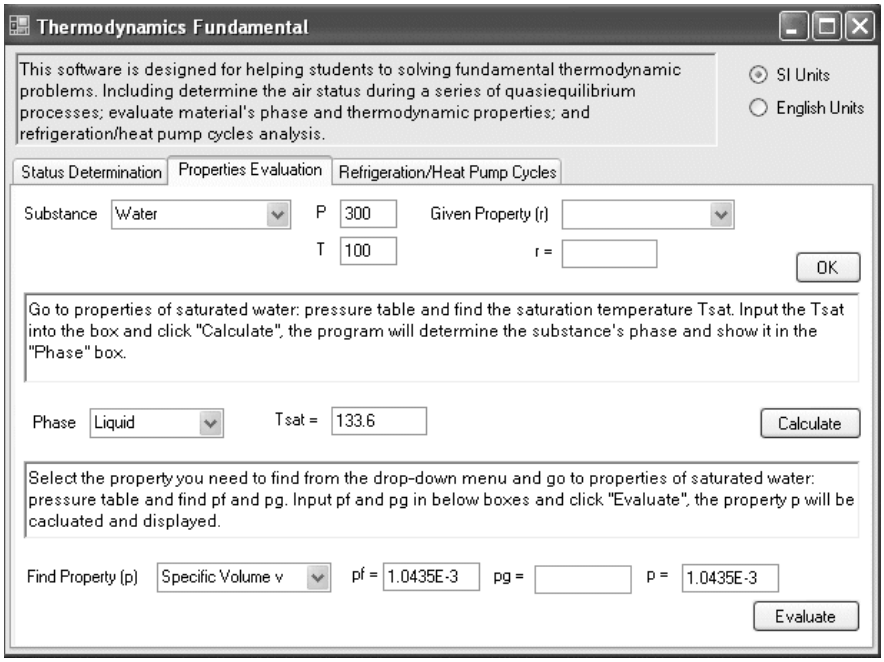

Figure 10. Find solution for 2) using the interface

Analysis of Basic Thermodynamic Cycles

Basic thermodynamic cycles include power cycles, refrigeration cycles, and heat pump cycles. Various thermodynamic cycles play prominent roles in many areas of application. Analyzing these cycles is very difficult because of the presence of complicating effects. A real thermodynamic cycle may have many processes and states. Engineers have to evaluate the characteristics for each process and determine the properties at each state using the method presented in the above section in order to analyze the entire cycle. The presented program only provides basic governing equations for the cycles from the perspective of the conservation of energy principle. Much more comprehensive software needs to be developed to study different cycles in greater detail.

In the following equations, W_{cycle} represents the net amounts of energy transfer by work; Q_{in} represents the heat transfer of energy into the system; and Q_{out} represents heat transfer out of the system. From different cycles, we have:

For power cycle

$$W_{cycle} = Q_{in} - Q_{out}, \text{ thermal efficiency } \eta = W_{cycle}/Q_{in} \tag{7}$$

For refrigeration cycle

$$W_{cycle} = Q_{out} - Q_{in}, \text{ coefficient of performance } \beta = Q_{in}/W_{cycle} \tag{8}$$

For heat pump cycle

$$W_{cycle} = Q_{out} - Q_{in}, \text{ coefficient of performance } \gamma = Q_{out}/W_{cycle} \tag{9}$$

In above equations the W_{cycle}, Q_{in}, Q_{out} can also be replaced by the rate form $\dot{W}_{cycle}$, $\dot{Q}_{in}$, and $\dot{Q}_{out}$, which represent the power or energy rate transferred by work and heat. The program is able to find W_{cycle} ($\dot{W}_{cycle}$), Q_{in} ($\dot{Q}_{in}$), Q_{out} ($\dot{Q}_{out}$), η, β, and γ for these cycles based on the inputs.

Example 3

A heat pump cycle whose coefficient of performance is 2.5 delivers energy by heat transfer to a dwelling at a rate of 20 kW. Determine the net power required to operate the heat pump, in kW.

The solution process of that example can be seen from Figs. 11 and 12.

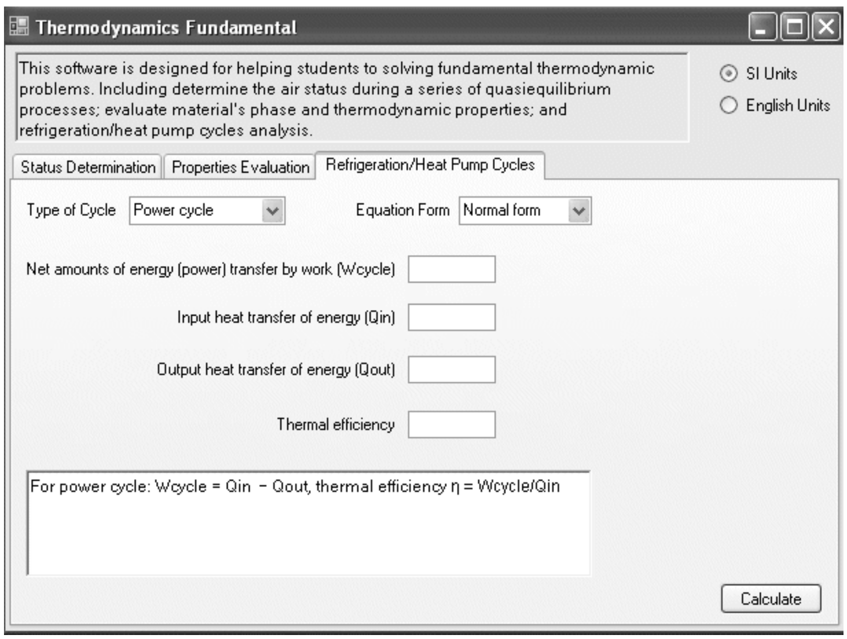

Figure 11. Main interface for analyzing thermodynamic cycles

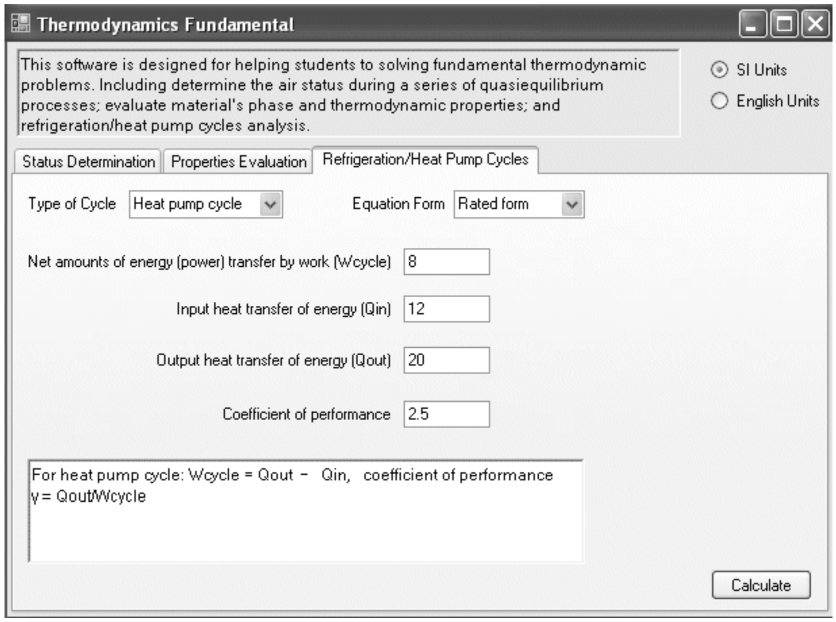

Figure 12. Solve problem 3 using the interface

Discussions and Conclusions

This paper presents courseware that can be used to solve fundamental problems in thermodynamic courses. Theories and algorithms related to the problem solving were implemented in the program, which was developed using C#. As validated by means of three application examples, the developed courseware can be used to solve typical thermodynamic problems, including: determine gas status, evaluate substance's thermodynamic properties, and analyze basic thermodynamic cycles from the perspective of the conservation of energy principle. Graphical user interfaces were designed for the courseware, through which a user can have a friendly conversation to the program. The proposed courseware can help engineering students to better understand basic thermodynamic principles, problem-solving approaches, as well as improving them the capability in solving analytical problems. Because of the advantages and efficiency of the developed courseware, it can be applied in thermodynamic education. Meanwhile, this paper also verifies that development and application of instructional courseware are simple but effective tools in enhancing teaching quality.

References

1. H. Canakci, "Pile foundation design using Microsoft Excel", *Computer Applications in Engineering Education*, 15(4) 2007 355-366.
2. Z. L. Kahn-Jetter, P. A. Sasser, "Using spreadsheets for studying machine design problems involving optimization", *Computer Applications in Engineering Education*, 5(3) 1997 199-211.

3. J. Sieres, J. Fernandez-Seara, "Simulation of compression refrigeration systems", *Computer Applications in Engineering Education*, 14(3) 2006 188-197.
4. A. Rivas, T. Gomez-Acebo, J. C. Ramos, "The application of spreadsheets to the analysis and optimization of systems and processes in the teaching of hydraulic and thermal engineering", *Computer Applications in Engineering Education*, 14(4) 2006 256-268.

YUCHENG LIU
Dr. Yucheng Liu currently serves as an Assistant Professor of Mechanical Engineering at the University of Louisiana at Lafayette. His research interests include structural impact and crashworthiness, computer modeling and simulation, mechanical and machine design, alternative energy technologies, numeric solutions to engineering problems, and engineering software development. Dr. Liu is a registered Professional Engineer in Louisiana and holds active membership in ASEE, ASME, and SAE.