Development of a Tutorial Software to Serve as a Teaching Aid for Power and Refrigeration Cycles

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ABSTRACT

The paper presents the development and application of a computer based tutorial software to aid instruction and improve problem solving skills in undergraduate "Thermal Systems and Economics" course offered by the Department of Mechanical Engineering. This course is a required design course in the Mechanical Engineering curriculum and an approved technical elective in the Chemical Engineering curriculum. It is offered during both fall and spring semesters with a class size of about 40 students. The expert tutor serves as a concise data base for key concepts learned in the course, and houses property tables and basic equations to interactively solve problems. The benefits of using this computer based instructional aid include: enhanced use of multimedia course materials, more creative thinking exercises for students, reduced time to master new concepts, and coverage of more materials in the course. The application of computer technology to facilitate interactive learning greatly enhances the instruction process. The concept of an expert tutor can be extended virtually to any engineering or science course at the undergraduate level.

INTRODUCTION

Thermodynamics is a core course in engineering curriculum throughout the nation. All engineering students are required to take the Basic Thermodynamics (usually known as Thermodynamics I) irrespective of their major discipline. Students majoring in Mechanical Engineering are required to take the Applied Thermodynamics (usually known as Thermodynamics II or Thermal Systems) where they apply the principles of thermodynamics to design power plants, reciprocating internal combustion engines, gas turbines and aircraft engines, and refrigeration and air-conditioning machinery. The design exercises usually require repeated calculations using properties of the working fluid (or fluids). The fluid properties are usually provided in a tabulated form and listed as a function of temperature and pressure. Equations correlating the properties are available only for simple substances such as an ideal gas. Calculation of fluid properties for different thermodynamic states usually sum up to a major portion of time needed to solve any problem. Hand calculations are tedious because of interpolation of tabulated data. Therefore, there is a great need for a computer-based property data bank where once a thermodynamic state has been defined by two independent properties, all remaining properties of the state can be readily obtained. In addition, if a student can set up a problem interactively in the computer and can execute the solution steps in an interactive fashion without tedious hand calculations, that definitely increases productivity on the part of the student as well as the instructor.

The use of computer for the instruction of thermodynamics is not entirely new. In fact most popular textbooks in this area have software diskettes that are sold with the book. Moran and Shapiro[1] uses a software package called Interactive Thermodynamics (IT). It can be used to input the model equations and solve them using a built-in solver. It has thermodynamic property data toolpads and process viewpads that allow the user to develop models of various thermodynamic systems. Black and Hartley[2] offered a software developed by Harper Collins College Software, in which the thermodynamic properties can be obtained for different fluids. Van Wylen et al.[3] offered a software called CATT. The software houses the thermodynamic properties of different substances. It has the graphical capability to visually illustrate the location of the thermodynamic state. Borgnakke and Sonntag[4] offered a second version of this software, called CATT-2, which is more user-friendly and allows pull down menus that permit to move among frames. Cengel and Boles[5] integrated EES (Engineering Equation Solver), which was independently developed to extract thermodynamic properties using equations of state and a non-linear equations solver to solve the process equations. EES has a good plotting package where graphs can be generated from the computed results.

There has also been attempts to use commercially available mathematical equation solvers such as MATHCAD or TK Solver for solving thermodynamic problems. Potter and Somerton[6] introduced the use of MATHCAD to model and solve thermodynamics problems. The use of TK Solver has been demonstrated in books by Burghardt and Harbach[7] and Jones and Dugan[8] . Even though the use of computer has been encouraged, a rigorous treatment of computer aided instruction has not been attempted in any work except for Potter and Somerton[6]. Particularly, a complete package where a software can augment the instruction by presenting in parallel the key concepts learned in the course and the application of those in an user friendly problem solution module was not available and prompted the developed of the present tutorial software.

The software developed here is not only for the calculation of thermodynamic properties, but a complete tutorial package designed to give the students with lecture highlights and additional multimedia course materials that are not available in the textbook, interactive examples where students can become familiar with how to set up and solve a problem, and a solver frame where they can develop their own model. The property manipulation has been made essentially fool proof where warning messages are displayed if certain combinations of data are inconsistent. The software currently contains data for water, R-134a, ammonia, and air. The software has been written using MICROSOFT VISUAL BASIC 3.0 and is compatible with other windows based applications.

PROGRAM STRUCTURE

The software has a modular structure. The WELCOME SCREEN connects to any of the following four modules: (1) LECTURES, (2) FLUIDS, (3) EXAMPLES, and (4)

SOLVER. The LECTURE module houses a number of modules containing main course topics and sub-topics as illustrated in Figure 1. Each of these instructional modules were developed using study materials from the text and other reference books. The size of these modules were optimized to provide a clear picture of the subject matter without incorporating excessive written materials. Essentially, the key concepts were highlighted and illustrated with practical applications. By clicking on any of these items, an user can access the text file that contain information about that item. In the present version of the software, students are allowed to open these files using MICROSOFT WORD and copy them to a file to help prepare their customized course note.

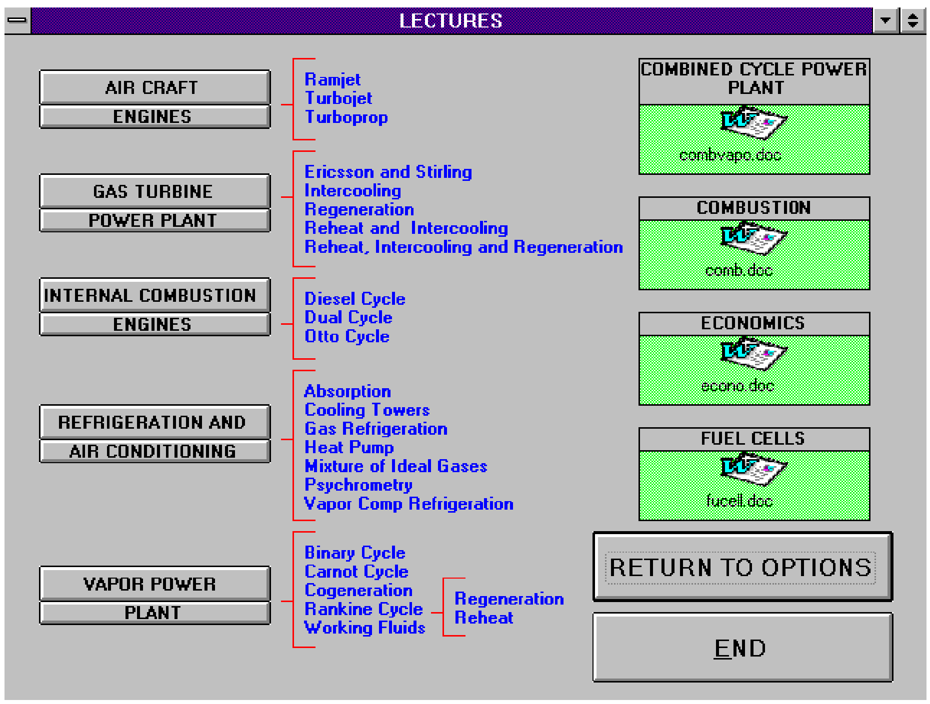

Figure 1 Items Covered in LECTURES module

The FLUIDS module currently contains properties data bank for four different fluids. These are water, air, Refrigerant-134a, and Ammonia. To specify the thermodynamic state of a substance, two independent properties are needed. The relevant properties are pressure, temperature, specific volume, internal energy, enthalpy, entropy, and quality of a liquid-vapor mixture. Once any of these two properties are specified, the program calculates and returns all other properties for that condition. This is illustrated in Figure 2. For air (or any ideal gas), the internal energy and enthalpy are dependent on temperature only. So, only one of these quantities need to be specified to get the relevant information for that condition. The FLUIDS module is the core of all thermodynamic calculations. So, this module is made accessible from a SOLVER screen or from EXAMPLES discussed later.

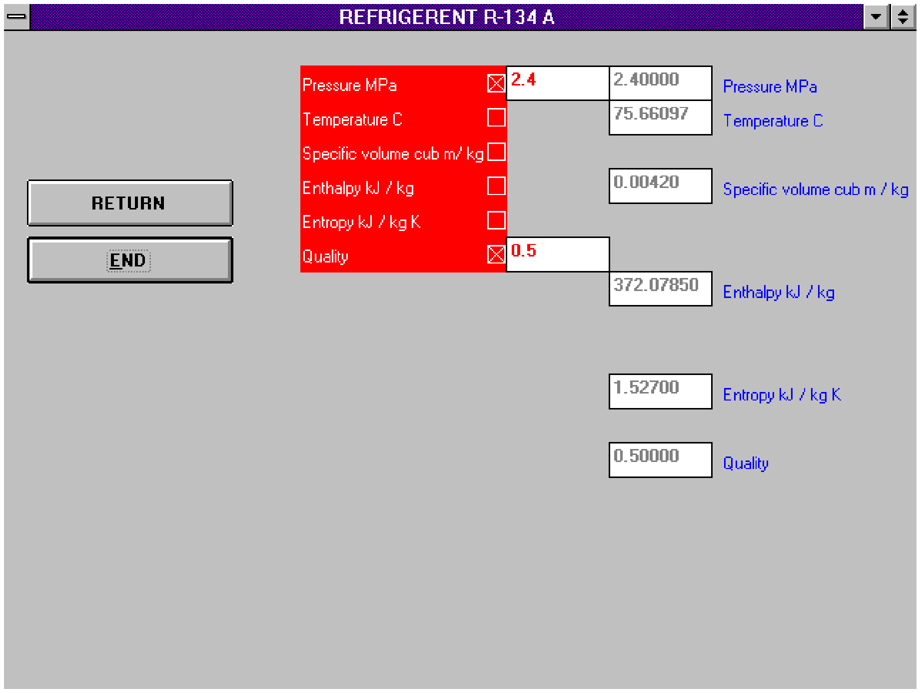

Figure 2 Fluid Properties with Two Conditions Specified

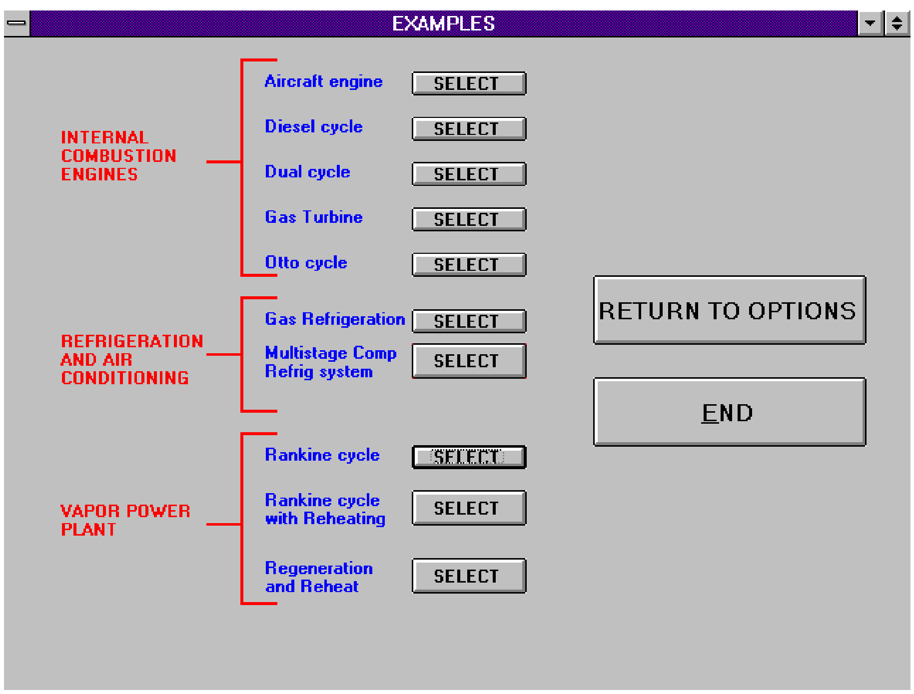

Figure 3 Items in EXAMPLES Module

The EXAMPLES module contains a number of examples as listed in Figure 3. The purpose of these examples is to illustrate the solution procedure for problems related to each course topic. An user is able to use these examples to become familiar with the application of course materials to real life problems. In addition, an user can use these examples as the starting point for solving complicated design problems. Figure 4 shows the computer screen which comes up when the example on “Rankine Cycle with Reheating” is selected. It may be noted that a student can start from a state that is completely specified and can walk over the entire cycle by following the step by step instructions. There are several calls to FLUIDS module to extract the water properties at different states during the thermodynamic cycle. This kind of interactive example is believed to stimulate interest in the subject matter and can save a lot of time on the part of a student to learn the course materials.

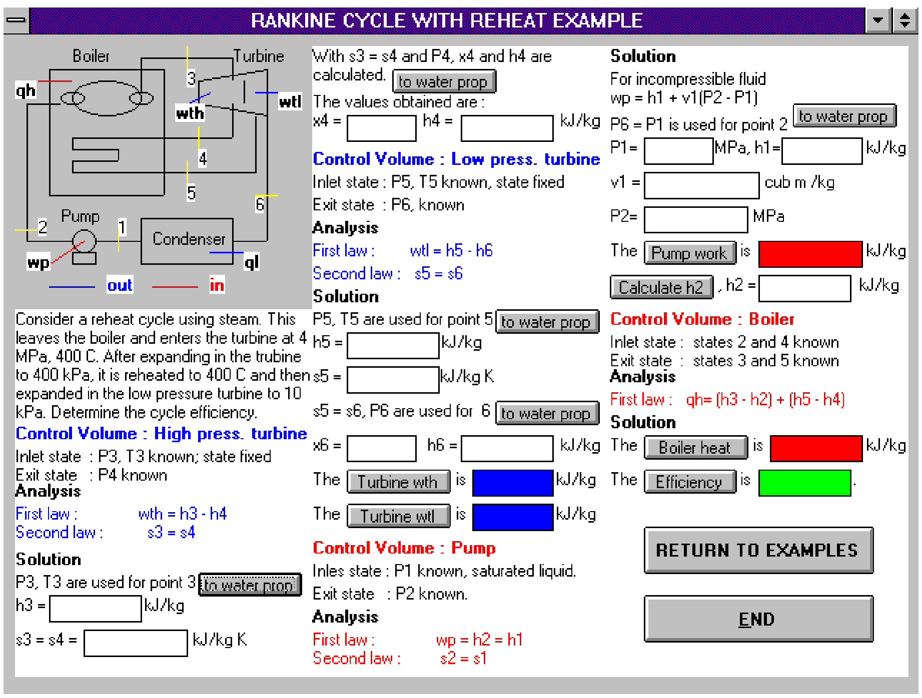

Figure 4 Example on Rankine Cycle with Reheat

The SOLVER module is used for the development of mathematical model and numerical solution of any closed or open cycle problem. After entering the SOLVER module and specifying the number of significant thermodynamic states and the working fluid, a work sheet as illustrated in Figure 5 is obtained. The number of rows on the right part of the work sheet corresponds to the number of processes in a particular system. The left part of the work sheet (property table) indicates the state points at the beginning and end of each of these processes. First, known properties corresponding to each thermodynamic state is entered. The connecting device or the process is entered in the column marked “el.” If there is an efficiency value associated with a turbine, compressor, or pump, the corresponding isentropic process is specified by “s” and the actual device and the efficiency is entered in the following line.

The property table is filled up by starting from a known state (usually point 1) and walking through the cycle. To get properties, the point number is entered in the specified box, and CHECK and PROP buttons are clicked in sequence. The purpose of the CHECK button is to make sure that the data to be transferred to the FLUIDS module are consistent and complete. In addition, it handles special situations like an isentropic process involving compressed liquid required for the calculation of pump work. To adjust for efficiency of a turbine, compressor, or pump, the element number is entered in the specified box, and a click on the CALC button returns the adjusted enthalpy in the property table. For an open feedwater heater, the mass fraction can be obtained by typing inlet and outlet states and clicking on the MASS button. The ERASER button can erase any specified line on the property table.

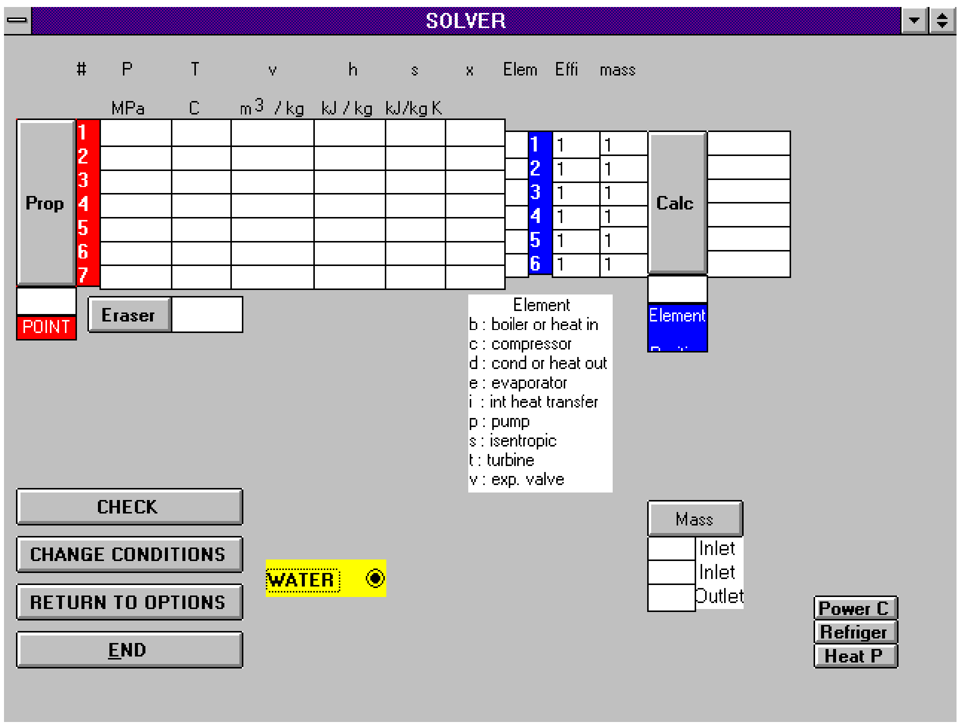

Figure 5 A Sample Worksheet for Problem Solution

Once the property table is completed, one can calculate the relevant work or heat transfer in each of the devices. This is done by entering the element number and clicking on the CALC button. After completing the work and heat transfer calculations for all elements, cycle efficiency or coefficient of performance can be obtained by clicking on the POWER CYCLE, REFRIGERATION, or HEAT PUMP button, as appropriate. From any location within the software, the RETURN button is used to return to the earlier screen, and the END button is used to exit the program. The entire software was written using VISUAL BASIC.

TEACHING ENHANCEMENT

It is expected that use of this tutorial software will enhance the teaching of the course by a great extent. The following are some of the obvious benefits.

1. Students will be able to learn the key concepts by browsing through the LECTURES module, running examples from the EXAMPLES library, and modeling and solving exercise problems using the interactive SOLVER. This will greatly reduce the study time required for the course.
2. The multimedia form of presentation of course materials will stimulate interest and will be more effective in retaining the ideas learned compared to any conventional form of instruction.
3. The use of a computer solver for numerical calculations will greatly reduce time required to solve problems, particularly design or open-ended problems where students are required to do several calculations.
4. The reduction of calculation time will allow students to be more creative in their assignments. They will be able to explore new and non-conventional ideas.
5. It will be possible to incorporate more design or open-ended problems in the course to better prepare our students for their professional career.
6. The software will allow more efficient use of class time and will foster more active learning exercises within the class.
7. The instructor will be able to upgrade the course contents without being limited by fixed class periods and students will be able to learn at their pace since the tutor will be available to them at all times.

USEFULNESS BEYOND THE PROPOSED COURSE

The concept of tutorial software described in this paper can be extended virtually to any engineering or science course at the undergraduate level. The most needy candidates will be engineering design courses that require the solution of open-ended design problems using concepts learned in the course. In a somewhat modified form, it can be made useful in other disciplines or in graduate courses.

CONCLUSIONS

The paper described an effort to put together a tutorial software for application in the "Thermal Systems and Economics" course offered at University of South Florida during regular fall and spring semesters. The interactive nature of the software stimulates students' interest in the subject matter and enhance the teaching by a great extent. It allows the coverage of materials that are usually not possible due to time constraints. Other benefits include reduced time for problem solution or design, higher retention of concepts learned, more practical applications of ideas learned in the course, enhanced creativity, and better preparation for professional career.

REFERENCES

1. Moran M.J., and Shapiro, H.N., Fundamentals of Engineering Thermodynamics, Third Edition, Wiley, New York, 1995.
2. Black, W.J., and Hartley, J.G., Thermodynamics, Third Edition, Harper Collins, New York, 1995.
3. Van Wylen, G., Sonntag, R., and Borgnakke, C., Fundamentals of Classical Thermodynamics, Fourth Edition, Wiley, New York, 1993.
4. Borgnakke, C., and Sonntag, R.E., Thermodynamic and Transport Properties, Wiley, New York, 1997.
5. Cengel, Y.A., and Boles, M.A., Thermodynamics, Third Edition, McGraw Hill, New York, 1997.
6. Potter, M.C., and Somerton, C.W., Engineering Thermodynamics, McGraw Hill, New York, 1996.
7. Burghardt, M.D., and Harbach, J.A., Engineering Thermodynamics, Fourth Edition, Harper Collins, New York, 1992.
8. Jones, J.B., and Dugan, R.E., Engineering Thermodynamics, Prentice Hall, Englewood Cliffs, N.J., 1996.

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