## Instructional Courseware Developed for Thermodynamics Course

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#### 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:

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

Isobaric process:

$$P_1 = P_2, W = P(V_2 - V_1)$$
(2)

Isometric process:

$$V_1 = V_2, W = 0$$
 (3)

Polytropic process:

$$PV^{n} = constant, W = \frac{p_{2}V_{2} - p_{1}V_{1}}{1 - n} \text{ or } W = \frac{mR(T_{2} - T_{1})}{1 - n} \text{ (ideal gas)}$$
(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  $P_1 = 180$ kPa,  $v_1 = 0.05$ m<sup>3</sup>/kg to  $v_2 = 0.03$ m<sup>3</sup>/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.

📰 Thermodynami	cs Fundamental		- DX
This software is des problems. Including processes; evaluate refrigeration/heat p	igned for helping students to solving t determine the air status during a ser material's phase and thermodynami Imp cycles analysis.	undamental thermodynamic ies of quasiequilibrium c properties; and	<ul> <li>SI Units</li> <li>English Units</li> </ul>
Status Determination No. of Processes [ Air Mass [	Properties Evaluation Refrigeration/Hea	t Pump Cycles	
Calculate		P-V (P-v) diagra	im

Figure 1. Main interface for determining gas status

Thermodynami This software is des problems. Including processes; evaluate refrigeration/heat p	cs Fundamental signed for helping students to solving fundamental thermodynamic g determine the air status during a series of quasiequilibrium e material's phase and thermodynamic properties; and ump cycles analysis.	- SI Units English Units
Status Determination No. of Processes [ Air Mass [ Process Type 1 Polytropic 2 Isometric 3 Isobaric Isothermal Isobaric Isometric Polytropic	Properties Evaluation       Refrigeration/Heat Pump Cycles         3       Type of Gas Air         P       V(v)         I       180         0.05       1.3         I       I         I       I	
Calculate	P-V (P-v) diagra	am

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

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

Other properties then can be calculated as

$$\mathbf{p} = (1 - \mathbf{x})\mathbf{p}_{\mathrm{f}} + \mathbf{x}\mathbf{p}_{\mathrm{g}} \tag{6}$$

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.

🔚 Thermodynami	cs Fundamental		-ox
This software is des problems. Including processes; evaluate refrigeration/heat p	signed for helping stu g determine the air st e material's phase ar ump cycles analysis.	dents to solving fundamental thermodynamic atus during a series of quasiequilibrium id thermodynamic properties; and	<ul> <li>SI Units</li> <li>English Units</li> </ul>
Status Determination	Properties Evaluation	Refrigeration/Heat Pump Cycles	
Substance	<b>Р</b> Т	Given Property (r)	OK
Phase	۲		Calculate
Find Property (p)	v	pf = pg = p =	Evaluate

Figure 4. Main interface for evaluating substance's properties

📰 Thermodynamics Fundamental	- DX
This software is designed for helping students to solving fundamental thermodynamic problems. Including determine the air status during a series of quasiequilibrium processes; evaluate material's phase and thermodynamic properties; and refrigeration/heat pump cycles analysis.	<ul> <li>SI Units</li> <li>English Units</li> </ul>
Substance       Water       P       Given Property (r)       Specific Volume v         T       200       r = 0.1         Go to properties of saturated water: temperature table and find rf and rg, input the rf and rg Click "calculate" and the program will determine the substance's phase based on the input	OK in below boxes. ts and calculate
the quality "x" if necessary.  Phase rf = rg = x =	Calculate
Find Property (p)         pf = pg = p =	Evaluate

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

📰 Thermodynamics Fundamental	- DX
This software is designed for helping students to solving fundamental thermodynamic problems. Including determine the air status during a series of quasiequilibrium processes; evaluate material's phase and thermodynamic properties; and refrigeration/heat pump cycles analysis.	<ul> <li>SI Units</li> <li>English Units</li> </ul>
Status Determination Properties Evaluation Refrigeration/Heat Pump Cycles	
Substance     Water     P     Given Property (r)     Specific Volume v       T     200     r = 0.1	ОК
Go to properties of saturated water: temperature table and find rf and rg, input the rf and rg Click "calculate" and the program will determine the substance's phase based on the input the quality "×" if necessary. Phase Liquid-Vapor rf = 1.1565E-3 rg = 0.1274 × =	in below boxes. ts and calculate Calculate
Find Property (p)         pf = pg = p =	Evaluate

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

	aynami	cs Fundament	al				
This softwa problems. I processes; refrigeratio	ire is des Including evaluate n/heat pi	igned for helpir determine the material's pha ump cycles ana	ng stu airst se ar lysis.	idents to so atus during id thermod	olving fundamental g a series of quasie lynamic properties;	thermodynamic quilibrium and	<ul> <li>SI Units</li> <li>English Units</li> </ul>
Status Deter	mination	Properties Evalu	ation	Refrigeratio	on/Heat Pump Cycles		
Substance	Water	*	P T	200	Given Property (r) r =	Specific Volume v	
the quality	"x" if ne	cessary.			•		
Phase Li	iquid-Vapo	h 🗸 Ic	= 1.1	565E-3	rg = 0.1274	x = 0.783	Calculate

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

🗄 Thermodynam	ics Fundamental			
This software is de problems. Includin processes; evaluat refrigeration/heat p	signed for helping stu g determine the air st e material's phase ar ump cycles analysis.	idents to solving fundamental atus during a series of quasie id thermodynamic properties;	thermodynamic quilibrium and	<ul> <li>SI Units</li> <li>English Units</li> </ul>
Status Determination	Properties Evaluation	Refrigeration/Heat Pump Cycles	]	
Substance Water	۷P	Given Property (r)	Specific Volume v 🛛 👻	
	Т	200 r =	0.1	ОК
10 i ii				
Go to properties o Click "calculate" a the quality "x" if ne Phase Liquid-Vap	f saturated water: terr nd the program will d cessary. or v ff = 1.1:	nperature table and find rf and letermine the substance's pha 565E-3 rg = 0.1274	Irg, input the rf and rg ir ase based on the inputs x = 0.783	and calculate

# Figure 8. Find solution for 1) using the interface

🔚 Thermodynamics Fundamental	- <b>-</b> ×
This software is designed for helping students to solving fundamental thermodynamic problems. Including determine the air status during a series of quasiequilibrium processes; evaluate material's phase and thermodynamic properties; and refrigeration/heat pump cycles analysis.	<ul> <li>SI Units</li> <li>English Units</li> </ul>
Status Determination Properties Evaluation Refrigeration/Heat Pump Cycles	
Substance         Water         P         300         Given Property (r)         ~           T         100         r =	
Go to properties of saturated water: pressure table and find the saturation temperature Tsa into the box and click "Calculate", the program will determine the substance's phase and s "Phase" box. Phase Tsat =	t. Input the Tsat how it in the Calculate
Find Property (p) v pf = pg = p =	Evaluate

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

📰 Thermodynamics Fundamental	-ox
This software is designed for helping students to solving fundamental thermodynamic problems. Including determine the air status during a series of quasiequilibrium processes; evaluate material's phase and thermodynamic properties; and refrigeration/heat pump cycles analysis.	<ul> <li>SI Units</li> <li>English Units</li> </ul>
Status Determination Properties Evaluation Refrigeration/Heat Pump Cycles	
Substance         Water         P         300         Given Property (r)           T         100         r =	✓ OK
Go to properties of saturated water: pressure table and find the saturation temperature Ts into the box and click "Calculate", the program will determine the substance's phase and "Phase" box. Phase Liquid V Tsat = 133.6	at. Input the Tsat show it in the Calculate
Select the property you need to find from the drop-down menu and go to properties of satt pressure table and find pf and pg. Input pf and pg in below boxes and click "Evaluate", the cacluated and displayed.	urated water: property p will be
Find Property (p) Specific Volume v v pf = 1.0435E-3 pg = p = 1.04	35E-3 Evaluate

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

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

For refrigeration cycle

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

For heat pump cycle

 $W_{cycle} = Q_{out} - Q_{in}, \text{ coefficient of performance } \gamma = Q_{out}/W_{cycle}$ (9) Proceedings of the 2013 ASEE Gulf-Southwest Annual Conference, The University of Texas at Arlington, March 21 – 23, 2013. Copyright©2013, American Society for Engineering Education 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  $W_{cycle}$  ( $\dot{W}_{cycle}$ ),  $Q_{in}$  ( $\dot{Q}_{in}$ ),  $Q_{out}$  ( $\dot{Q}_{out}$ ),  $\eta$ ,  $\beta$ , and  $\gamma$  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.

📰 Thermodynamics Fundamental	-ox
This software is designed for helping students to solving fundamental thermodynamic problems. Including determine the air status during a series of quasiequilibrium processes; evaluate material's phase and thermodynamic properties; and refrigeration/heat pump cycles analysis.	<ul> <li>SI Units</li> <li>English Units</li> </ul>
Status Determination Properties Evaluation Refrigeration/Heat Pump Cycles	
Type of Cycle Power cycle V Equation Form Normal form V	
Net amounts of energy (power) transfer by work (Wcycle)	
	Calculate

Figure 11. Main interface for analyzing thermodynamic cycles

trigeration/heat	pump cycles analysis.	Refrigeratio	n/Heat Pur	np Cycles		
ype of Cycle He	at pump cycle 🗸	Equatio	on Form R	ated form	~	
Net amounts of ene	ergy (power) transfer by wo	ork (Woyole)	8			
	Input heat transfer of	energy (Qin)	12			
	Output heat transfer of er	nergy (Qout)	20			
	Coefficient of p	performance	2.5			
For heat pump o	vcle: Wcvcle = Qout -	Qin, coeff	ficient of p	erformanc		

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.

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