Journal of Engineering and Applied Sciences 8 (1): 29-37, 2013
ISSN: 1816-949X

Challenges in Teaching and Learning Fundamentals of Thermodynamics in Engineering

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Abstract: Introduction to engineering thermodynamics is a core subject for almost all engineering students. It covers the fundamentals of thermodynamics including properties of pure substances, energy transfer and the 1st law of thermodynamics, entropy and the 2nd law of thermodynamics and thermodynamic applications of power and refrigeration cycles. Thermodynamics has always been labeled as a tough and abstract subject by the majority of engineering students. There are a few factors why this tough subject phenomenon still weighs heavily on the students' minds. First, the students fail to understand the basic concepts of thermodynamics itself. Secondly, most students are not skilful enough in acquiring data from property diagrams and tables such as the steam table. When they do not understand the basic concepts and do not know how to obtain relevant data they will not be able to solve the particular problem. Another factor that students usually raised and complained about is that they have to memorize too many equations. Furthermore, the students fail to relate what they learn from one chapter to another. Based on these factors, the lecturers responsible to teach this course have to take it as a challenge to counter the students' negative perception by strengthening the basic understandings on the concepts and laws of thermodynamics and assisting the students in acquiring thermodynamic data to solve thermodynamic problems. Hopefully, a thermodynamic course will be famous as an interesting subject not as a tough subject as it is now in the future.

Key words: Engineering education, entropy, 1st law of thermodynamics, outcome based education, property tables, 2nd law of thermodynamics

INTRODUCTION

In engineering education, the subject of thermodynamics is usually taught in two different and consecutive courses. The 1st course covers the basics of thermodynamics in relation to the 1st and 2nd law of thermodynamics including entropy and a brief introduction on the applications of thermodynamics in steam cycles, refrigeration and heat transfer. The 2nd course on the other hand delves into phase and chemical equilibriums in chemical engineering. Thermodynamics has become a customary course for the chemical and mechanical engineering undergraduates but that is no longer the case for the civil and electrical engineering majors. However, the Faculty of Engineering and Built Environment of Universiti Kebangsaan Malaysia has taken an approach where it is compulsory for all engineering majors to take common faculty courses including basic thermodynamics, introduction to electrical engineering, material science and basic applied mechanics in the 1st year. The objective of introducing the common subjects to the 1st year students is to produce graduates who are able to work in various fields and who possess engineering knowledge outside their own fields.

Teaching thermodynamics to students from various engineering fields is a challenge that must be faced by the lecturer. This course has a history of being labeled as one of the difficult courses. According to the experience of one of the researcher while studying in the University of Nottingham (United Kingdom), this course has also been branded as a tough subject among the English students. Therefore, the tough subject phenomenon is not something that only circulates among local students here but also globally. In addition, through the researchers experience of teaching this course for almost 10 years, several factors have been identified as to why the tough subject phenomenon still weighs heavily on the students' minds.

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FACTORS TOWARDS TOUGH SUBJECT LABELLING

The 1st and most serious factor is the students fail to understand the basic concepts of thermodynamics itself. As an abstract course that requires various logical assumptions and reasonable considerations to be made, students are afraid to make a certain simplification or do not know which assumption to make in order to simplify a given thermodynamic problem. An example of such an assumption is that at a low pressure, i.e., 1 bar a gas exists at an ideal state (Cengel and Boles, 2007; Smith *et al*., 2005). However, this assumption is illogical if the gas is at a pressure of 200 bar or if the liquid or solid phases of the substance are present. Similarly if the students were asked to solve a problem involving an open system or control volume, the usual assumption that has to be made to solve this problem is that the fluid flowing through the open system is experiencing a steady state process, i.e., its properties will not vary with time. Therefore, the students must be encouraged to come up with suitable and logical assumptions.

Secondly, most students are not skilful enough in acquiring data from tables or property diagrams, such as steam table. Even if the students do understand the basic concepts of the 1st and 2nd law of thermodynamics, they will not be able to solve the problem if they do not know how to obtain relevant data. Now-a-days, there is a lot of user-friendly softwares being made available by thermodynamic textbook researchers that can be used to obtain the required thermodynamic data. Herawan *et al*. (2004) have developed software aimed at solving thermodynamic problems, data searching and thermodynamic equations using computer aids whereas Dixon has introduced in his lecture the Engineering Equation Solver (EES) software to obtain thermodynamic data. Both researchers found that by using this type of software, it saves time and increases the level of understanding and interest among the students in the basic concepts of thermodynamics while giving them a chance to appreciate thermodynamic applications in the engineering world. According to them, abolishing the usage of tables can help in overcoming students' perception of the thermodynamics course as an old science that has no connection with the applications of computer-based skills. Mathias (2005) uses Excel® software which is included in the Aspen software, in modeling a process and estimating specific properties in thermodynamic applications in chemical engineering.

Although, there are many advantages put forward by researchers (Herawan *et al*., 2004) in support of abolishing the usage of tables, the researchers feel that the traditional way of acquiring data using the property tables should be maintained and exposed to the students before the usage of any software such as the EES, being introduced to them. This will enable the students to be more appreciative when using the computer after they have been exposed to the traditional method of acquiring data. If they were directly exposed to the usage of the computer to find data or solve problems, the researcher fears that they will treat the computer or software as a black box that can identify input and produce output without understanding the process inside the black box and consequently fail to explain and justify the answers they obtain.

Another factor that students usually brought up and complained about is that they have to memorise too many equations. However, the actual problem is that the students do not know which suitable equation to apply to a specific problem. Most difficult equations are usually given along with the question. As an example, if the students are clear with the system used, i.e., whether it is a closed system or control volume and the type of fluid used, i.e., whether it is a pure substance where the data can be found in the property tables or it is in a solid, liquid or gaseous phase that is not included in the property table then they will not be confused anymore on which equations to use. Furthermore, the students fail to relate what they learn from one chapter to the next chapter. They often assume that there is no connection between the chapters because the question most often asked when their final examination is around the corner is from which topic the question is going to be extracted. They fail to simplify the concepts learned as something that are related to one another.

Next, some engineering students, especially those who major in electrical and civil engineering, assume that the thermodynamics course carries no weight in their future careers. They associate this course only with chemical and mechanical engineering which is similar to how engineering students in other fields view the introduction to electrical engineering course. Based on this factor, the lecturers responsible to teach this course have to take it as a challenge to change the students' negative perception before carrying on with the thermodynamics syllabus. Abdullah *et al*. (2004) suggest that the thermodynamics course should be taught using the top-down approach to increase the students interest in this course. Traditionally, the thermodynamics course and many other courses are taught by starting on the basic concepts and ending them up with the applications of those concepts in engineering. With the top-down approach, the thermodynamics course will start with the exposure to the thermodynamic applications in various engineering fields in parallel to the introduction to the basic concepts of thermodynamics along with the explanation on the progress of the thermodynamic application. This suggestion can probably be implemented in order to increase students appreciation of the course. The lecturer responsible must convince the students that the field of thermodynamics is not something that is completely segregated from the daily life of a human being. The thermodynamic applications used in our daily life such as in refrigerators, air-conditioning systems, car engines, electricity generation from power plants, the human body systems and others have to be exposed to the students to attract their interest. In chemical engineering, many new fields are being brought forward by Wu (2004) that demand the application of thermodynamics such as environmental control, manufacturing elements for nano-structure materials and protein crystallization.

Lastly at some universities, the large population of students per lecture is also a contributing factor in the ineffectiveness of teaching thermodynamics and many other engineering courses as well. Most engineering courses involve calculations, requiring the lecturers to explain on the whiteboard and not only depend on presentations using computer applications such as the Power Point. A large audience such as 200 students per lecture, does not only lessen the interactions between the students and the lecturers but it also cause the lecturers to loose control over their lectures, especially while explaining a rather difficult concept. The students sitting at the back will face some problems when they are not able to see the explanation written on the whiteboard. More thermodynamic problem examples must also be given in a lecture. This does not mean the lecturers must show a detailed solution for every problem given but what is more important is the guidance in solving the problem. In addition while giving out problem examples, many questions can be put forward to the students to train them in thinking and justifying the steps to be taken and the solutions obtained. Therefore, the number of students per lecture should be 50-70 students in order to enhance the interactions between students and lecturers.

Through the short experience of one of the researchers in teaching the basic course of thermodynamics for 10 years, there are some guides that the researcher will recommend in the next study that can be used as guidance for the lecturers to teach and the students who follow the course.

FUNDAMENTALS OF ENGINEERING THERMODYNAMICS

The fundamentals to engineering thermodynamics course is a basic course that exposes 1st year engineering students to the basic concepts of thermodynamics such as the properties of pure substances, the 1st law of thermodynamics, entropy and the 2nd law of thermodynamics and on the thermodynamic applications of steam cycles, refrigeration and heat transfer. In keeping with the aspiration of the Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia (UKM) which has adopted learning based on the Outcome Based Education (OBE) starting from the 2005/2006 session several learning outcomes for this course have been identified. By the end of this basic thermodynamics course students are expected to be able to:

- Understand the basic concepts of thermodynamics, such as temperature, pressure, system, property, state, process, cycle and equilibrium
- Determine and differentiate the properties of substances based on property diagrams and property tables
- Apply the 1st law of thermodynamics and conservation of mass principle to both closed and control volume systems
- Apply the 2nd law of thermodynamics and entropy in analyzing the thermal efficiencies of heat engines such as Carnot and Rankine cycles and refrigerators through the refrigeration cycles

In general, the syllabus covered in the basic thermodynamics course can be summarized by the flow chart shown in Fig. 1. It is mainly about two basic principles of thermodynamics which are the 1st and 2nd law of thermodynamics (Borgnakke and Sontag, 2009; Cengel and Boles, 2007; Moran and Shapiro, 2008; Smith *et al*., 2005). The 1st law of thermodynamics also known as conservation of energy principle or energy balance (Cengel and Boles, 2007) is a principle stating that energy can neither be created nor destroyed during a process but can only change forms or in terms of formula, it can be simplified as:

$$\begin{pmatrix}\text{Total energy}\\ \text{entering the system}\end{pmatrix} - \begin{pmatrix}\text{Total energy}\\ \text{leaving the system}\end{pmatrix} = \begin{pmatrix}\text{Net change in the total}\\ \text{energy of the system}\end{pmatrix}$$

or;

$$E_{in} - E_{out} = \Delta E_{system} \quad (1)$$

Equation 1 can be applied for both types of systems, i.e., closed and control volume systems (also known as an open system). Each system has its own solution method using the 1st and 2nd laws of thermodynamics. For closed system, Eq. 1 can be further reduced to:

$$Q - W = \Delta U + \Delta KE + \Delta PE \quad (2)$$

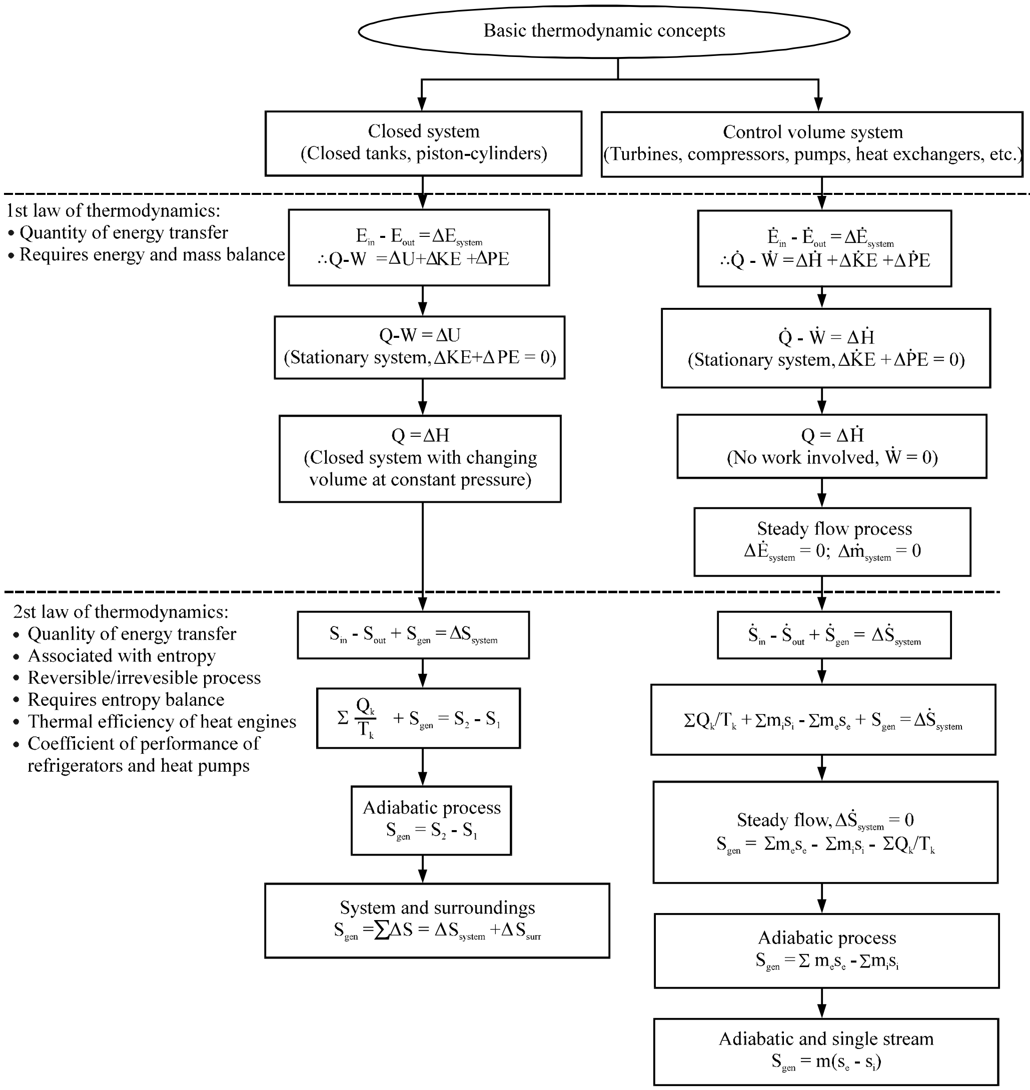

Fig. 1: Summary of the syllabus covered in the fundamentals of engineering thermodynamics

Where:

- Q = The heat to be transferred into the system (heat input)
- W = The work done by the system (work output)
- ΔU = The change of internal energies of the system
- ΔKE = The change of kinetic energies of the systems
- ΔPE = The change of potential energies of the systems

For control volumes, the 1st law of thermodynamics is generally represented in Eq. 1 can be simplified as follows:

$$\dot{Q} - \dot{W} = \Delta\dot{H} + \Delta\dot{KE} + \Delta\dot{PE} \quad (3)$$

with $\Delta\dot{H}$ representing the rate of enthalpy change and the dots on each symbols (similar definition as in Eq. 2 indicating the rates for each type of energy. For the control volumes, it involves with mass flow in and out of the system as in a compressor, turbine or nozzle application. An assumption of control volumes undergoing steady-flow processes can be applied to simplify the solution of thermodynamic problems involving control volumes. Since, the control volumes involves mass flowing in and out of the system, conservation of mass principle (also known as mass balance) as in Eq. 4 should be first defined to the control volumes before Eq. 3 can be used. The conservation of mass principle is defined (Cengel and Boles, 2007) as the net mass transfer to ($\dot{m}_{in}$) or from ($\dot{m}_{out}$) a control volume during a time interval is equal to the net change ($\Delta\dot{m}_{CV}$) in the total mass within the control volume during the time interval:

$$\dot{m}_{in} - \dot{m}_{out} = \Delta\dot{m}_{CV} = \underbrace{dm_{CV}/dt}_{0\ (\text{steady-flow})}$$
$$\therefore \sum_{in} \dot{m} = \sum_{out} \dot{m} \tag{4}$$

Both Eq. 2 and 3 representing the 1st law of thermodynamics of respective closed system and control volume have similar forms except the term for internal energy, ΔU is being replaced by the enthalpy term, ΔH for the control volume. It means that to solve thermodynamic problem using the 1st law of thermodynamics on a closed system and control volume, thermodynamic data in terms of internal energy and enthalpy, respectively should be sought. Unless the closed system undergoes a constant pressure process (Fig. 1), Eq. 2 can be further reduced to:

$$Q = \Delta H + \Delta KE + \Delta PE$$

According to the definition of enthalpy:

$$\Delta H = \Delta U + P\Delta V \tag{5}$$

Additionally, the 2nd law of thermodynamics states that any process proceeds in a certain direction and not in the reverse or in any other direction (Cengel and Boles, 2007; Moran and Shapiro, 2008). The 1st law places no restriction on the direction of a process and only states that energy can change its form from one type to another. In other words, the 1st law regards with the quantity of energy but satisfying the 1st law does not ensure that the process can actually occur. This is where the 2nd law of thermodynamics comes in to determine the quality of energy or decide whether the process will progress or otherwise. A process cannot occur unless it satisfies both the 1st and 2nd law of thermodynamics. Even though the problem may ask about the efficiency of a thermodynamic cycle, the solution still demands for the application of the 1st law before determining the energy transfer involved.

Furthermore, the 2nd law of thermodynamics is closely related to entropy. To determine whether a process can proceed, the reversibility of a process or the efficiencies of heat engine and refrigerator performance, an entropy balance should be performed on the process or the thermodynamic cycle. The entropy balance (Cengel and Boles, 2007) on a system relates the entropy change of a system (ΔS_{system}) during a process which is equal to the net entropy transfer across the system boundary (S_{in}-S_{out}) and the entropy generated (S_{gen}) within the system:

$$S_{in} - S_{out} + S_{gen} = \Delta S_{system} \tag{6}$$

Equation 6 can be applied to the two types of closed system and control volume. Entropy can be transferred to or from a system as it crosses the boundary by two mechanisms of heat transfer and mass flow. For a closed system, entropy can only be transferred through heat transfer, since the mass of closed system is always kept constant. Therefore, Eq. 6 can be simplified as:

$$\sum \frac{Q_k}{T_k} + S_{gen} = \Delta S_{system} = S_2 - S_1 \tag{7}$$

Where:
Q_k = The heat transfer across the system boundary
T_k = The absolute temperature of the system

For control volumes since, it involves with the mass flow, the 2nd law of thermodynamics as expressed in Eq. 6 can be elaborated as:

$$\sum \frac{\dot{Q}_k}{T_k} + \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \dot{S}_{gen} = \Delta\dot{S}_{system} \tag{8}$$

With the s_i and s_e indicate the respective entropy into and out of the system.

All the Eq. 2, 3, 7 and 8 can be further reduced into more simplified equations for both systems as shown in the flow chart of Fig. 1, for applications in other conditions, such as stationary system and adiabatic process. Hence, students should understand both thermodynamic laws to help them in solving problem.

GUIDELINES ON THERMODYNAMIC DATA ACQUISITION

In solving a thermodynamics problem students should also know how to acquire data, especially from property tables, based on the information given in the problem statement. After the system involved has been determined, the next step is to obtain data, such as specific volume, enthalpy, entropy and internal energy. Based on Fig. 2, data required is based on the type of fluid used, i.e., whether it is categorized as a pure substance such as water, refrigerant, ammonia or air. For pure substances, data can be obtained from their property tables and diagrams available in most thermodynamics textbooks (Borgnakke and Sontag, 2009; Cengel and Boles, 2007; Moran and Shapiro, 2008). On the other hand, for impure substances or fluids with no property tables, the next step would be to determine whether the fluid is in the solid, liquid or gaseo us phase. Solid and liquid here

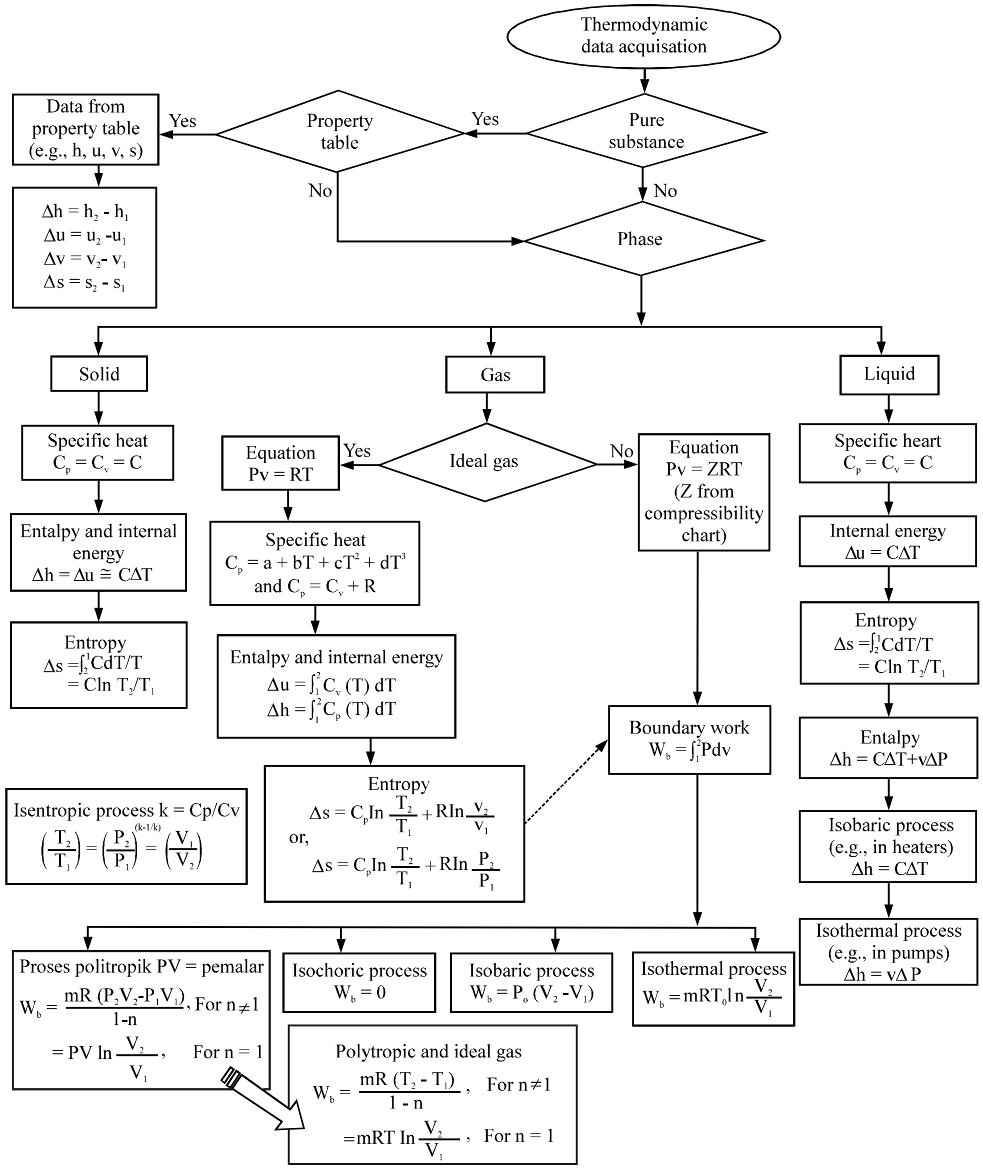

Fig. 2: Guidelines to obtain data and to determine Δh, Δu, Δs and boundary work, W_b

are referred as incompressible fluids. If the fluid is in the gaseous phase, the ideal gas assumption can be used if the gas is at low pressure. If it is at a high pressure, the compressibility factor, Z must be taken into consideration. If it exists in the liquid and solid phases, it must be solved using suitable equations as shown in Fig. 2. Figure 2 simplifies the equations concerned to determine the change in enthalpy, internal energy, entropy and boundary work.

For pure substances such as ammonia, water, nitrogen and refrigerants (R12, R134a and R141b) where the data can be obtained from property tables, such as the steam table for water, a systematic guideline on how to obtain suitable data must be demonstrated to students. Students who understand the basic concepts of thermodynamics but are not skilful in obtaining data, especially from property tables will fail to pursue on solving a thermodynamic problem.

The property tables can be divided into 4 main groups (Fig. 3), i.e., saturation table, superheated table, compressed liquid table and saturated vapour-solid table (Cengel and Boles, 2007). The saturation table can be further divided into two categories whereby the data is respectively arranged according to temperature and pressure. For most pure substances, their property tables usually consist of the saturation and superheated tables. Only water has all the 4 types of property tables. Figure 4 explains the steps need to be taken when referring to a property tables to obtain the required data. The 1st step is to refer to the saturation table at given T, P or y property (representing h, u, s, v). If the properties given are within the conditions set for the superheated steam phase then the next step is to refer to the superheated table in order to obtain other properties or information

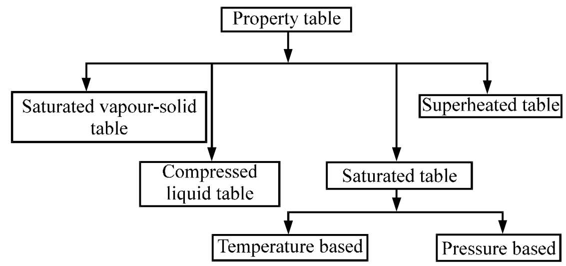

Fig. 3: The categories of poroperty tables

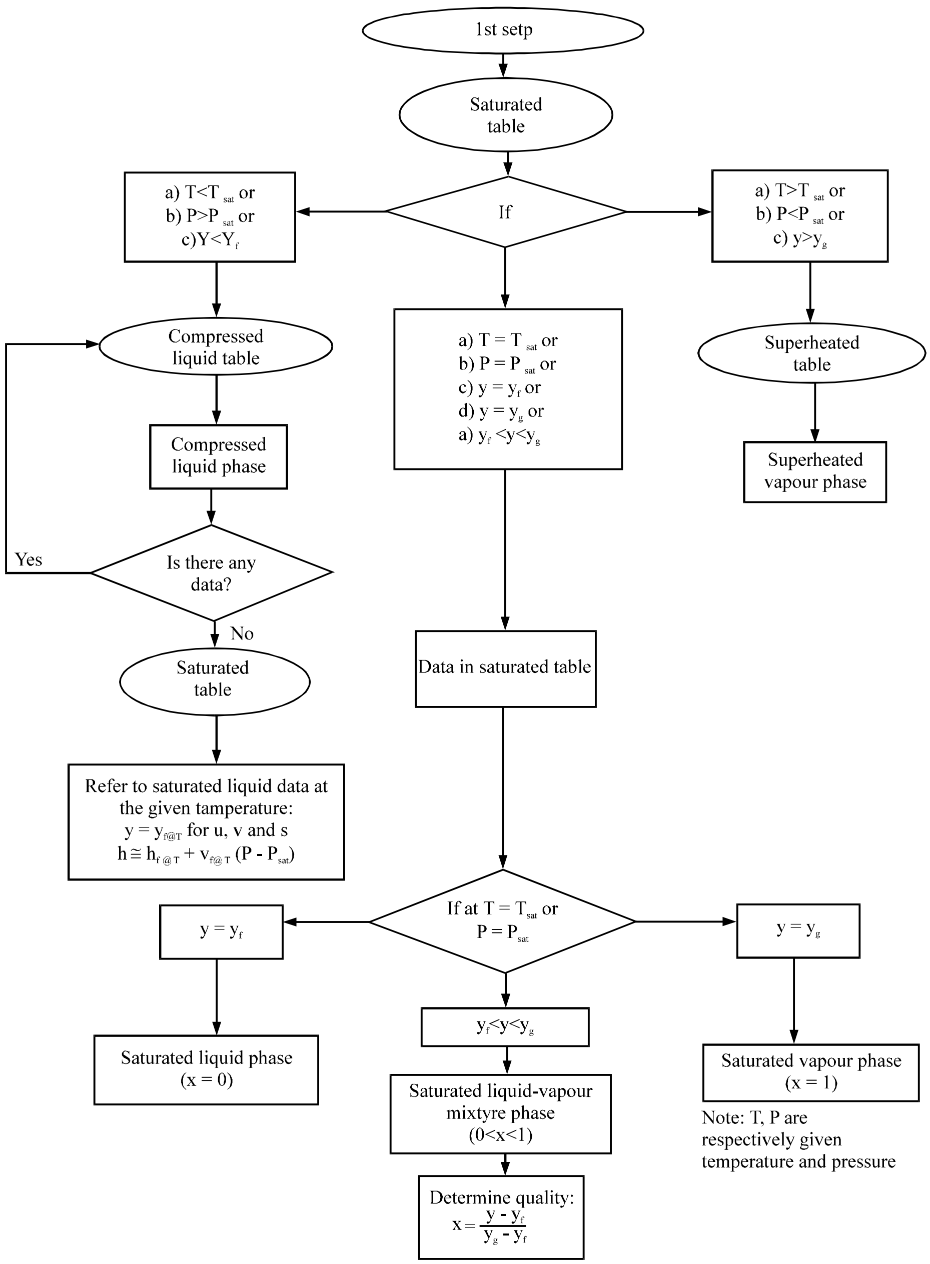

Fig. 4: Sequence of steps to be taken when referring to property tables

required. Whereas if the properties given are within the conditions set for compressed liquid then the compressed liquid table must be referred to in order to obtain other additional information. However, not all substances have data in the form of property tables for their compressed liquid phase. For example, water substance possesses compressed liquid data but it is only limited to data at a pressure starting from 5 MPa (Cengel and Boles, 2007). Therefore, if there is no available data or compressed liquid table for the substance required, compressed liquid data for that substance can still be obtained by referring to the saturation table and estimating the data needed by correlating it to the saturated liquid data at the given temperature:

$$y \cong y_{f@T} \quad (9)$$

where, y represents the properties of internal energy, u entropy, s and specific volume, v. For enthalpy, h which is highly de pendent on pressure variation:

$$h \cong h_{f@T} + v_{f@T}(P - P_{sat}) \quad (10)$$

Where:

$h_{f@T}$, $v_{f@T}$ = The enthalpy and specific volume of saturated liquid at a given temperature, respectively

P, P_{sat} = The given and saturated pressures of the substance

Furthermore, as shown in Fig. 4 when all the saturation conditions are fulfilled there are three phases that will possibly be formed, i.e., saturated liquid, saturated steam or saturated liquid-steam mixture phase. If the y property given is the same as the saturated liquid property, y_f listed in the saturation table at the given T or P then the phase formed is the saturated liquid phase in which the quality, x defined as the ratio of vapor mass to the total mass at this time is equal to zero. When it is the same as the saturated vapor property, y_g at the given T or P then it exists as the saturated vapor where the quality is equal to unity. Whereas if the property given exists between the saturated liquid property, y_f and saturated steam property, y_g then the phase formed will be a mixture of saturated liquid-steam and its quality will be between zero and unity. The quality for the saturated liquid-steam mixture phase can be determined through Eq. 11:

$$x = \frac{y - y_f}{y_g - y_f} \quad (11)$$

Where, y can represent u, v, h and s. Apart from being trained in obtaining data from the property tables, students should also be exposed to data acquisition from the property diagrams. The correlation between data obtained from the property tables and its position on the property diagrams, especially P-v, T-v, T-s and h-s must be explained so that the students can visualize and identify them on the property diagrams when a fluid is experiencing a change of state (Smith *et al.*, 2005).

CONCLUSION

The great challenge for lecturers who are responsible to teach thermodynamics course is to gain and increase the interests of their students in learning and understanding the concept of basic thermodynamics. The big task is to remove the tough subject phenomenon from their students' minds and also convince them that the thermodynamics is not a segregated world from the daily lives. Lecturers are responsible to provide proper guidance and clarify any misunderstandings of basic concepts of thermodynamics to their students so that they are confidence in solving any thermodynamic problem. Hopefully, thermodynamic course will be famous as an interesting subject not as a tough subject as it is now in the future.

ACKNOWLEDGEMENT

The researchers gratefully acknowledge Universiti Kebangsaan Malaysia for supporting this action research project (UKM-PTS-2011-006).

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