Bottom-Up Approach Of Teaching Classical Thermodynamics In The Faculty Of Chemical And Natural Resources Engineering, UTM.

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1.0 Introduction

The Faculty consists of five departments that offer five bachelor of engineering programmes. The curricula of four of the programmes namely chemical, chemical-bioprocess, chemical-polymer, chemical-gas, consist of the same core subjects. The petroleum engineering curriculum has the same thermodynamics subject as the other four but the core subjects are different.

Loverude, Kautz, and Heron 2002 presented their work on the difficulty of teaching the first law of thermodynamics to physics students. The main problem was that students did not recognise the situation or system for which the first law of thermodynamics could be applied. In a sense, their problem was similar to ours where all the concepts given in the earlier topics were lost to the students when they have reached the application topics in the last part of the subject.

The main characteristic of bottom-up approach is to first teach students the basic components of a system or concepts that increase in complexity. The final system is then taught after about 75 percent of the semester is over. Students often complained of how the simple systems or concepts did not help them very much to understand or be able to design the final system.

Whale and Cravalho, 1999 dealt with the difficulty in transmitting thermodynamic principles by using two approaches. One approach was to use design projects such as a refrigerator to present the various thermodynamics topics and how those topics were applied. Another approach was more complicated in that the curriculum of the programme was modified to integrate a few subjects. We felt that improving the teaching technique for the bottom up approach or use the top down approach in the form of design projects was easier to implement.

The programmes in FCNE do not by design end up producing graduates who work or design power plants, refrigeration units or any of the systems taught in classical thermodynamics. They also do not use the power cycles or cooling cycles in other subjects. While their grasp of the final application may not be good, much of the concepts or basic units taught in thermodynamics will be used by the students in other subjects of their programmes.

Our paper examines the curricula of the programmes in the faculty and shows that the bottom-up teaching approach in classical thermodynamics is appropriate for our students.

2.0 Methodology

The topics whether directly taken from thermodynamics or in a modified form are identified. For example, hydrostatic pressures are directly used in drilling engineering to calculate pressures in the well bore while the behaviour of oil and gas in the reservoir can be inferred from steam behaviour. Energy balance is directly applied in heat transfer studies. In most subjects, the concepts presented in thermodynamics are used in a modified form to apply to chemical engineering or petroleum engineering systems. The percentage of each core subject in which thermodynamics topics are taught is then estimated. Since the application may be direct or indirect and perhaps more than one thermodynamics topics are applied at one time, the total estimated time for a particular subject might exceed 100 %. Only taught core subjects are analysed, which means laboratory and projects are not included.

3.0 Results and discussion

Tables 1 and 2 in the Appendix summarise the results of analyses of the two curricula. Column one presents the main topics covered in thermodynamics.

3.1 Petroleum Engineering

There are 16 taught courses in petroleum engineering and 10 subjects apply thermodynamics topics.

3.1.1 Basic concepts

The basic concepts that are taught early in semester such as units, hydrostatic pressure and balance of forces are not new to our students. These topics have been taught in physics. Nevertheless, applying pressure balances and hydrostatic pressure calculations to totally different systems are not always easy for many students. Therefore, covering the topic once more in thermodynamics is expected to help them in other subjects. Oilfield units, which are a combination of Imperial units and uniquely oil industry units, are generally used in the oil industry, and therefore, core petroleum subjects are taught using oilfield units. However, many petroleum journals and European companies require metric units. This section helps our petroleum students to strengthen their ability to use metric units.

Hydrostatic pressures are used directly in many petroleum subjects especially in drilling and reservoir engineering. In drilling, hydrostatic pressures in the well bore are balanced with the pressures exerted by the drilling mud to prevent a blowout. Appropriate mud weight has to be used and calculated to achieve the balance. Hydrostatic pressure exerted by water column differs from oil column due to the density difference. The depth at which oil and water meet or contact will result in a break in the pressure versus depth plot. This depth or the water oil contact is used as the lower boundary of the oil reservoir. Consequently, the size of the oil reservoir is defined by the water oil contact. Although the time estimated in reservoir engineering is 15 % for pressure calculations, the time belies the importance of pressure. Almost all calculations in other sections of the subject involve the use of pressures. Similarly, pressure is the main parameter in drilling engineering and well completions calculations.

3.1.2 Phase behaviour

Steam is only used in petroleum engineering as part of steam injection enhanced oil recovery of heavy oil. Since Malaysian crude oils are light, this topic is omitted in enhanced oil recovery which is also an elective subject. However, the relationship between pressure, volume and temperature (PVT) of steam is an introduction to the more complex multicomponent crude oil and natural gas behaviour. Apart from the differences in the phase diagrams of a pure substance and a multicomponent system, the terminology may also be different. For example, bubble point and dew point are used in place of the saturation points in thermodynamics. While specific volume is emphasised in thermodynamics, density is the more important parameter for our students.

Two phase PVT behaviour forms a significant portion of reservoir engineering and rock and fluid properties syllabi, accounting for 70 and 50 % respectively. The 70 % estimate in reservoir engineering was based on the use of PVT behaviour to calculate oil in place, recovery, reserves and drive mechanisms. As stated in the methodology, the sum of the estimated time for reservoir engineering is more than 100 % because more than one thermodynamics topic are used in some reservoir engineering topics.

3.1.3 First law

Steady state and unsteady state flow through pipe or well bores are used mostly in drilling, production, well completion and gas engineering. Well testing and reservoir engineering apply flow in porous media that entails some change in the equations used. In petroleum engineering, the equations are overwhelmingly volume based. Consequently, instead of mass balance, volume balance is taught. Subsurface flows are usually assumed to be isothermal. Changes in temperature, which involve energy balances, are mostly dealt with in the gas engineering subject. Valves, pumps and compressors are the steady state devices used in several of the subjects. Separators for separating oil gas from the wells make use of PVT and steady state mass flow.

3.1.4 Second law and cycles

There are no applications of cycles and second law in petroleum The need for these topics petroleum engineering is more for graduating a ‘complete’ engineer rather than any particular use in petroleum engineering undergraduate programme.

3.2 Chemical Engineering

Chemical Engineering students study thermodynamics in the second semester of an 8 semester programme.

3.2.1 Basic Concepts

Basic concepts such as temperature, pressure and unit have been taught in physics and also material balance. The topic is considered as a revision. Almost all calculations in Chemical engineering deal with temperature and pressure. Unlike petroleum engineering, chemical engineering deals with pressure drop rather than hydrostatic pressure per se. The calculation of pressure drop is important in design of equipment such as reactor or distillation column. Therefore, it is estimated that most of the subjects in Chemical Engineering used this topic for less than 5 %. Nevertheless, it is important that students are able to grasp the topic in order to understand other subjects.

3.2.2 Phase Behaviour

Phase behaviour is an important topic in Chemical Engineering especially when dealing with separation processes. Although this topic in thermodynamics deals with pure substance, its importance, for example in the concept of saturation, is the basis for multicomponent system. Phase behaviour for multicomponent forms a significant portion of separation processes I and II syllabi, accounting for 60% and 30% respectively. In separation processes I, a significant portion of the processes such as distillation, absorption and extraction deal with phase behaviour.

Ideal gas and real gas calculation are also important in chemical engineering subjects. It is estimated around 10% of these subjects use the concept of ideal or real gas. For example, in pollution control or reaction engineering, the ideal gas calculations are used in calculations of gas flow rate.

3.2.3 First Law

The topic of the first law is one of the most important topics in thermodynamics. In thermodynamics, the first law calculation only involves devices such as heat exchanger, compressor, pump etc. In heat exchanger calculation, students are required to calculate heat duty or amount of steam required. Students are not exposed to the mechanical aspect of these devices. Students sometimes hardly visualize the equipment and the importance of it. Many calculations such as heat transfer, mass transfer, reaction and separation processes require the knowledge of first law. Therefore, it is estimated that more than 20% of the syllabi in chemical engineering subjects involve the first law.

3.2.4 Second Law of Thermodynamics

Chemical engineering students study chemical thermodynamics where the concept of entropy, a quantity that resulted from the second law of thermodynamics, is used. However, it constitutes less than 5% of the subject.

3.3 Suggested Changes to the Syllabi

Thermodynamics suffer from lack of interest among students because it is usually viewed as separate and unrelated to chemical engineering and petroleum engineering subjects, in addition to being known as an abstract subject. Our students lack exposure to the mechanical aspects of the devices unlike mechanical engineering students for whom thermodynamics form a core subject. Therefore, our students require presentation that is more pictorial and more discussion on the uses of each device. In doing so, students will have a better preparation for classes such as drilling engineering and gas engineering.

The students will also appreciate the importance of thermodynamics when they are able to see the processes and equipment in the course of their study. If this situation can be remedied, the bottom-up approach can be enhanced and greatly improved.

Interest in the learning of thermodynamics can be created by visits to plants and factories during the semester.

4.1 Conclusions

Both the petroleum and chemical engineering curricula apply three quarters of the thermodynamic topics from bottom up. The maximum estimated percentage of any subject that applies thermodynamics is 75 %. From the analysis, it was shown that bottom up approach is appropriate for FCNRE. Improvement is suggested for more in-depth mechanical aspects of the steady state devices are given.

References

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Appendix

Table 1: Application of Thermodynamics Topics in Petroleum Engineering

Thermodynamics topics Bottom up arrangement	Subjects	Details	Estimated percentage of subject that used thermodynamics topics
1) Basic concepts -Hydrostatic pressure -pressure balance -Units	Introduction to Petroleum Engineering	Conversion of units	Less than 5 %
	Reservoir Rocks and Fluid Properties	Calculation of capillary pressures,	Less than 5 %
	Drilling Engineering,	Pressure balance for mud weight calculations	15 %
	Reservoir Engineering	Hydrostatic pressures for gas-oil contact, water-oil contact	15 %
	Well Completion	Balance of pressures for casing and tubing design	25 %
2)Phase behaviour -gas and liquid phase behaviour -physical properties of pure substances -gas laws real gas and ideal gas behaviour Z factor estimation	Introduction to Petroleum Engineering	Simple cases of reservoir topics using PVT	10 %
	Reservoir Rocks and Fluid Properties	PVT behaviour of oil and gas, PVT diagrams	50 %
	Principles of Petroleum Refining	Multicomponent crude oil properties	Less 5 %
	Reservoir Engineering	Z factors to estimate gas reserves, crude oil and gas phase behaviour for recovery and oil in place calculations, drive mechanisms	75 %

3) 1^{st} law -Energy balance -Mass balance -Steady state flow concepts -Steady state devices -Unsteady state flow	Introduction to Petroleum Engineering	Simple drilling concepts using pressure balance and flow properties	10 %
	Drilling Engineering	Steady state flow through tubing and annulus, control valves	25 %
	Petroleum Production Engineering	Multiphase flow in pipes and wells. Choice of pumps, control valves, chokes.	75%
	Well completions	Subsurface facilities design involves flow through tube, valves, perforations	25 %
	Well testing	Steady and unsteady flow analyses	30 %
	Gas engineering	Gas steady state and unsteady state flow in pipelines, gas compressors and metering	60 %
	Reservoir engineering	Mass balance for close reservoirs, steady state and unsteady state conditions for water influx	30%
4) 2^{nd} Law & cycles	N/A	N/A	

Table 2: Application of thermodynamics topics in chemical engineering

Thermodynamics topics Bottom up arrangement	Subjects	Details	Estimated proportion of subject that used thermodynamics topics
Temperature and pressure, -Hydrostatic pressure balance	Almost all core subjects	Temperature, pressure, unit	Less than 5% of the subjects
2) Phase behaviour -concepts & diagrams -gas laws real gas and ideal gas	Mass Balance	Ideal and real gas	10%
	Chemical Eng. Thermodynamics	Phase equilibrium	40%
	Separation Processes I	Phase equilibrium	60%
	Separation Processes II		30%
	Chemical Reaction Eng.	Ideal and real gas	10%
	Pollution Control	Ideal and real gas	10%
3) 1st law -Energy balance -Mass balance Steady state flow concepts -Steady state devices -Unsteady state flow	Mass and Energy balance		100%
	Chemical Eng. Thermodynamics	Energy balance	20%
	Separation Processes I	Energy balance	40%
	Separation Processes II	Energy balance	30%
	Chemical Reaction Eng.	Energy balance	35%
	Plant synthesis	Energy balance	30%
	Pollution control	Energy balance	30%
	Process control	Energy balance	10%
	Transport processes		20%
4) 2nd law	Chemical Thermodynamics	Entropy	Less than 5 %
5) Power and refrigeration cycles			insignificant