Chemical Engineering 373
Chemical Engineering Thermodynamics

Dr. Dean Wheeler

Winter 2014

MWF 10 am, 250 CTB

Instructor Objective

As an instructor, my objective is to support your goals to serve other people in professional, family, church, and community life. I want to help you become competent engineers who can apply the principles of thermodynamics. True confidence in any sphere of life come from working, studying, practicing, struggling, and overcoming significant challenges. True satisfaction comes from helping others along the way. This semester we have some hard climbs to make and some wonderful vistas to enjoy together. We will need God's help every day.

Course Introduction

> "A theory is more impressive the greater the simplicity of its premises, the more different are the kinds of things it relates, and the more extended its range of applicability. Therefore, the deep impression which classical thermodynamics made upon me. It is the only physical theory of universal content which, within the framework of applicability of its basic concepts, I am convinced will never be overthrown." Albert Einstein [quoted in M.J. Klein, *Science* 157: 509, 1967]

This course covers *classical thermodynamics*, which describes heat and work interactions and changes of state for materials at or near equilibrium. While initially developed in the 1800s to describe the behavior of steam engines, the field has since been generalized to describe a wide range of physical and chemical systems. From a few basic laws and principles, one can derive a multitude of general relationships and predictions. It is a foundational science in chemical engineering.

Application of thermodynamic relationships to real systems requires the empirical measurement and tabulation of thermophysical properties of materials of interest. Thus, physical property measurement and correlation is an important branch of thermodynamics. There is also a branch of thermodynamics that attempts to describe departure from equilibrium and rates of change; however in this class we will deal almost exclusively with equilibrium states of matter.

Classical thermodynamics is based on mathematics and physical observation and requires no assumption about the microscopic nature of matter. That is why classical thermodynamics continues to be useful despite substantial changes in our understanding of atoms and molecules. However, the companion discipline of *statistical mechanics* relates macroscopic properties to atomic behavior and can in many cases predict and explain material properties from molecular-level interactions. Most current research in the field of thermodynamics includes elements of statistical mechanics.

In summary, classical thermodynamics *can*

- Predict the amount of heat or work associated with a process or change, for pure components and mixtures (e.g. the work to compress a gas).
- Predict changes in condition or state (e.g., temperature, pressure, volume, phase, chemical composition, and energy) for materials in the process.

- Predict relationships between two different properties (e.g. vapor pressure and heat of vaporization)

Classical thermodynamics *cannot*

- Describe the condition or state of individual atoms or molecules.
- Predict physical behavior of a material without some previous experimental measurements.
- By itself predict a rate or how long some change will take, because this requires describing departure from equilibrium.

Course Objectives

This class is not your first exposure to thermodynamics (and hopefully will not be your last). As students and instructor, we will be learning and relearning this material together. The main objective of this course is to develop your ability and confidence to apply the principles of thermodynamics to solve problems in three areas:

1. Changes of state, including for open systems
2. Phase equilibria
3. Chemical equilibria

A secondary objective is for you to gain experience using computational tools (e.g. Mathcad) to solve real-world engineering problems. Specific skills and knowledge are described in the list of *Student Outcomes* below.

Mastery of the material in this course means much more than being able to plug numbers into an equation. There is virtually an infinite number of problems and applications that thermodynamic analysis can address, and so you should learn to analyze problems starting from fundamental relationships. This is quite different from expecting to pull a pre-digested equation out of a book to solve every problem, and students who overcome this urge will experience less frustration and improved performance. Your goal should be to practice this kind of analysis until it becomes automatic.

Text

The required text is Smith, Van Ness, and Abbott, *Introduction to Chemical Engineering Thermodynamics*, 7th ed., McGraw-Hill, 2005.

Coursework Activities

You should spend approximately 9 hours per week on this class: 3 in the classroom and 6 on outside work. Some students will need to put in more time than this to earn the grade they desire. Coursework activities include the following:

- **Assignments.** Completing homework assignments is essential for your learning. Assignments are due at the beginning of class on the indicated due date. Late homework will not be accepted for credit unless approved by the instructor given a compelling reason, such as illness. For instance, if you are taking an unofficial spring break, plan on submitting your homework before you leave.

Problems in thermodynamics often require solving simultaneous and implicit equations. Also, a large number of properties and constants are used. Consequently, to complete many of the assignments you will need to use Mathcad, which provides solving capabilities and automatic unit conversions. You should review principles covered in ChEn 263 (there is a tutorial on the department website as well).

Solutions to the homework sets will be made available on Learning Suite after you have submitted the assignment. I have instructed the TAs to give points for "reasonable effort" on problems, so no matter how many points you earn on a problem you should still carefully review the solution key to ensure that you know how to properly solve the problem or to identify a more efficient solution procedure.

- **Quizzes.** Occasionally there will be a short quiz covering concepts, including reading assignments. Missed quizzes cannot be made up except in cases of illness.

- **Active Learning.** You should bring your textbook and a calculator to class each day. Each day you must sit next to at least one other student so you can do pair-share activities. You may be called upon to present your ideas and solutions to the rest of the class. I encourage you to review your notes after class each day and come to office hours to clear up uncertainties, instead of waiting to do this at exam time. Studying as part of a group is encouraged and is an important engineering survival skill.

- **Exams.** My assessment method in this class is different than you are used to. It is built on the philosophy that learning new skills requires repeated opportunities for feedback. There will be a short midterm exam approximately every two weeks (five total), and each will count for approximately 7% of your final grade. I encourage you to use them to improve your learning process throughout the semester so you will be prepared for the final.

  Secondly, I want you to do more than "sort of get" the material, but instead to *master* a set of problems that represents the breadth of thermodynamics. Each midterm and the final will be 100% multiple choice, open book, closed notes, and will be given in the testing center. Each will contain a mixture of concept and quantitative questions, with most of the points from the latter. In order to maximize your learning and mastery, each midterm will have a *pre-exam* and a *post-exam*. The pre-exam contains 4–5 practice problems. The actual quantitative exam problems will be chosen from these practice problems, though input numbers and other changes will be made so that they are not exactly identical. Because the exams are multiple choice (no partial credit) and closed notes, you must fully master a quantitative problem in order to get credit on the exam. On the other hand, by providing the quantitative problems before you take the test, I am giving you an opportunity to master them in a lower pressure environment. The post-exam is a chance for you to re-solve any missed quantitative problems after the exam and get 50% credit for correct answers. Final exam quantitative problems will, like for the mid-terms, be selected from the practice problems given out during the semester.

- **Department Requirements.** This course is designated to ensure you complete department requirements for attending Dean's Lectures and meeting with your academic advisor. Not doing either of these things will result in a one-third letter grade reduction (e.g. B to B-).

  The Dean's lectures are planned for 11 am on the first Thursday of February, March, and April, in the JSB Auditorium (Rm 140). You must attend at least *two* lectures to fulfill the requirement. If illness or your work schedule do not permit you to attend the regular Dean's Lectures, your remedy is to view a recording of the lecture on the college website (if available) or substitute attendance at a graduate-level research seminar sponsored by our department or another engineering or science department.

To ensure that you are prepared for the senior year in Chemical Engineering, you are required to meet with your academic advisor this semester. During this meeting, items such as elective offerings, graduation clearances, and required courses will be discussed.

Grading

The final course score will be weighted as follows:

Assignments and quizzes	30%
Midterm exams ($\approx$ 7% each)	35%
Final exam	35%

I generally use a straight scale in assigning course grades, with some minor modifications to boundary lines based on my perception of course difficulty and student effort. The average grade in the class is likely to be a B.

Contact Information and Office Hours

Instructor/TA	phone	email
Dean Wheeler	801-422-4126	dean_wheeler@byu.edu
James Low		low.bicycle@gmail.com
Peter Shiozawa		pshiozaw@gmail.com
Chien-Wei "Ben" Chao		s943536@gmail.com

	Mon	Tues	Wed	Thur	Fri	Sat
9:00 AM 9:30 AM		Peter		Peter		
10:00 AM 10:30 AM	ChEn 373		ChEn 373		ChEn 373	Peter
11:00 AM 11:30 AM						
12:00 PM 12:30 PM	Peter	James	Peter	James	James	
1:00 PM 1:30 PM		James	Dr. Wheeler	James	Dr. Wheeler	
2:00 PM 2:30 PM						
3:00 PM 3:30 PM	Dr. Wheeler			Ben		
4:00 PM 4:30 PM	Ben	Ben	Ben		Ben	
5:00 PM 5:30 PM						

- TA office hours will generally be in either 206 CB (TA office) or 308 CB (computer lab), depending on how computer-intensive the homework assignment is. If you are looking for the TA, check both places.

- You may visit Dr. Wheeler in my office (350H CB) during office hours or by appointment. If there is another student in my office, please let me know you are waiting. You are welcome to visit me at other times, though there is no guarantee I will be available.
- The instructor and TAs will use Learning Suite messaging as a means to communicate with you outside of class. Learning Suite will likewise be used for posting course documents, including assignments, notes, and answer keys. BYU Gradebook will be used for posting student scores—you are responsible to verify that your scores are accurately recorded.

Class Rules and Ethics

- I expect compliance with the BYU Honor Code, including the Dress and Grooming Standards.
- Homework study groups are encouraged, but each student should write up his or her solutions independently. By this I mean that students should teach each other how to solve the homework problems and may compare solution procedures, but should not copy others' work nor allow their own work to be copied. Likewise for computer work, two or more individuals are not permitted to work jointly on a spreadsheet or worksheet, which is printed or copied and turned in separately—you must work each problem on a computer by yourself.
- When you put your name on an assignment, quiz, or exam, you are representing it as your own work. Under this principle, it is dishonest and a violation of the Honor Code to obtain or view homework assignments, computer files, quizzes, and exams from students who have previously taken this course. Using any unauthorized solution keys, whatever the source, is similarly dishonest. If you have any of these materials, please get rid of them and eliminate the temptation.
- BYU policy on use of course materials: "All course materials (e.g., outlines, handouts, syllabi, exams, quizzes, PowerPoint presentations, lectures, audio and video recordings, etc.) are proprietary. Students are prohibited from posting or selling any such course materials without the express written permission of the professor teaching this course. To do so is a violation of the Brigham Young University Honor Code."

Ch En 373 Student Outcomes

Each course in the chemical engineering major has a set of associated *student outcomes* or *competencies* determined by the department. For most topics your proficiency will be assessed by means such as homework assignments, quizzes, and exams. Listed below are the competencies for this course.

- Level of Assessment

  1 - Student is exposed to material but not necessarily assessed

  2 - Competency is assessed in course

  3 - Competency is assessed in course and again before graduation

- Usage

  I - (Introductory) The competency is covered at an introductory level

  M - (Major) Major exposure to competency occurs in the course

  R - (Review) Competency taught previously is reviewed.

  P - (Programmatic) The competency occurs widely throughout the curriculum and is not specific to a particular course.

Competency	Level	Usage	Description
3.1.2	2	M	Students will be able to solve steady-state, overall, material and energy balances for systems which include one or more of the following: recycle, multiple units, chemical reactions.
3.1.5	3	M	Students will be able to read mixture phase diagrams (liquid-liquid and VLE) and construct mass balances from them using the lever rule, tie lines, etc.
3.1.6	3	M	Students will be able to set up and solve simple transient energy balances.
3.2.1	3	M	Students will understand the phase behavior of pure substances in relationship to the variables T, P, and density (including vapor pressure, critical point, freezing line, triple point, etc.).
3.7.1	3	M	Students will be able to apply the first law of thermodynamics to closed and open systems (including energy, work, and heat transformations in process units such as tanks, turbines, compressors, valves, etc.).
3.7.2	3	M	Students will be able to apply solution thermodynamics fundamentals to solve VLE, LLE, SLE, and GLE problems including bubble point, dew point and flash calculations.
3.7.3	3	M	Students will understand the fundamental principles of chemical reaction equilibria including extent of reaction, equilibrium constant and its temperature-dependence, equilibrium conversion.

Competency	Level	Usage	Description
3.7.4	2	M	Students will be able to use equations of state and corresponding states correlations in the determination of properties.
3.7.5	2	M	Students will understand and be able to apply the concepts of heat capacity, latent heat, heat of reaction, heat of combustion, and heat of formation.
3.7.6	2	M	Students will understand the concept of entropy and the second law of thermodynamics and be able to apply the second law to closed and open systems.
3.7.7	2	M	Students will understand the fundamental concepts of solution thermodynamics including chemical potential, fugacity, activity, partial molar properties, ideal solutions, and excess properties.
4.9	1	P	Students will demonstrate effective interpretation of graphical data.
5.5	1	P*	Students will be able to use modern property databases to assist in problem solving.
6.1	3	P*	Students will demonstrate an ability to solve engineering problems.
6.4	2	P	Students will exhibit critical and creative thinking skills for analysis and evaluation of problems and cause-effect relationships.
6.6	2	P	Students will be able to rationalize units, make order of magnitude estimates, assess reasonableness of solutions, and select appropriate levels of solution sophistication.
7.2	2	R	Students will understand and have a basic knowledge of how safety and environmental considerations are incorporated into engineering problem solving.
10.4.2	3	M	Students will be able to set up and solve single-stage flash calculations.
10.6.1	2	M	Students will be able to perform design (sizing) calculations for turbines and compressors (e.g., involving delta H, delta S, work, heat, efficiencies).
10.6.2	2	M	Students will be able to perform energy conversion calculations for Rankine power and compression refrigeration cycles.
12.8	1	P	Students will demonstrate effective reading of technical material.