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BEER, BOOZE, AND BIOFUELS: AN INTRODUCTION TO CHEMICAL ENGINEERING

By

Kayla Revelle,
Jacob Lambert,
and
Kelly Kopchak

Submitted in Partial Fulfillment
of the Requirements for
Graduation with Honors from the
South Carolina Honors College

May 2017

Approved:

__________________________________
Dr. Ed Gatzke
Director of Thesis

__________________________________
Dr. John Weidner
Second Reader

__________________________________
Steve Lynn, Dean
For South Carolina Honors College
Honors Thesis Project
Beer, Booze and Biofuels: An Introduction to Chemical Engineering
Kayla Revelle, Jacob Lambert, Kelly Kopchak
Thesis Adviser: Dr. Ed Gatzke
Second Reader: Dr. John Weidner
Defense Date: April 17, 2017
Introduction and Motivation

The goal of this thesis project was to provide the layout, curriculum, and scheduling for an introductory course regarding chemical engineering for non-majors. Throughout the course of our studies in chemical engineering and engineering in general it had come to our attention that there were many myths regarding the classes and curriculum. We had heard countless times things such as “I am glad I’m not an engineering major”, “those classes seem so hard and boring”, or “It’s all math”. The purpose of this project and class was to dispel those myths and show non-majors what chemical engineering is all about. This new class covers a wide variety of chemical engineering topics that are covered during a typical 4-year curriculum, but on an introductory level. The project focuses heavily on the introductory level chemical engineering classes and briefly discusses more complex subjects learned in the later years of study. BBB is not extremely math heavy as our students will not have the same background as an average engineering student. Instead this course focuses on the overall concepts and ideas of engineering with a few basic mathematical operations. The laboratory course work focuses on principles of measurement and observation. The required write ups focus on mastery of excel and plotting graphs. The goal is to give the students a feel for what it is like to be an engineer and to gain better understanding of what exactly chemical engineers do. Students should walk out of the class with a new appreciation for the engineering creations present in everyday life.

Approach and Methodology

This project work began by revisiting all of the essential chemical engineering classes that we have taken over the past few years. We went through the curriculum for each class and determined the most important and essential information that was learned in each course. This involved brainstorming basic concepts and determining how we could break these down into the
bare essentials needed to teach someone who had never taken a college level math or science course. This was also accomplished by reaching out to the professors who traditionally teach each of these respective courses and working with them to establish the main objectives of each class. Once we compiled this information into an organized topic spreadsheet, we created an applicable class schedule and curriculum. We split each topic into categories that reflected in which lecture they will be taught. We then sorted each of these lectures into a semester long schedule. The next step, which was the bulk of this project work, was to create a textbook-like document where each topic was explained in detail along with examples. Similarly, another huge part of the project was creating all of the PowerPoint presentations to go along with each lecture topic. For these two steps, we relied heavily on the chemical engineering knowledge that we have amassed over the past 4 years. We also conducted research by consulting textbook and internet sources to augment our own knowledge. This was a good refresher for us as well to revisit topics that are basic to us now but gave us much trouble when we were first starting out.

The topics covered over this semester long course include:

- Types of alcohol
- Unit operations and conversions
- Significant figures
- Chemical engineering basics
- Energy
- Reactions
- Thermodynamics basics
- Distillation and separation techniques
- Chemistry basics
- Introduction to fluid mechanics
- Heat transfer
- Chemical process design
A laboratory aspect will also be included as part of this course curriculum. This will give students a chance to experience some of the physical aspects of chemical engineering that are discussed during the lecture portion of the class. We are proposing a lab schedule with approximately 7 labs over the course of the semester in order for this course to count as a science lab credit. These lab topics include:

- Microsoft Excel Basics
- Basics of Measuring
- Distillation
- Fermentation
- Filtration
- Pumps
- Heat Conduction

The excel, measuring, and fermentation labs were created from scratch using principles that we have learned in class and in labs during our own course work. Conversely, the pumps, distillation, heat conduction, and filtration labs were adapted from the lab procedure and analysis developed by Dr. James Ritter and Charles Holland as part of the chemical engineering laboratory I and II curriculum. We greatly simplified these labs but used the same basic procedure and some of the background and analysis sections. It was difficult to adapt such complex labs to a simple level that can be performed by students with no laboratory background. We went through and fine-tuned all of the procedures to lay out exactly what was expected of each student. Furthermore, it is expected that a TA will be in the lab at all times to answer any questions that should arise.

As this class is intended to give students a taste for the engineering world, there is a group work component to the course work. Students are expected to participate in a number of
class time group activities designed to test engineering and problem solving ability. This teamwork component is key as working in groups is an integral part of the engineering profession. Finally, to give students an idea of some real world large scale engineering processes a number of field trips will also be scheduled to various engineering related facilities. These will include: a local brewery visit, a local distillery visit, and a visit to a biofuel manufacturer.

**Project Expectations**

The main course objectives for students taking this course would be to have a new understanding of chemical engineering. This course will mainly be marketed to business and arts and sciences majors who do not have a strong background in science or math. This course will try to focus on the essentials of engineering while also being taught in an unconventional engineering fashion. In order to keep the students engaged, it is important to have lectures that go beyond the conventional way of a teacher lecturing straight from a PowerPoint. In order to achieve this, we plan to include in class activities that go along with the lecture topics. Another big component of engineering is working in a team. We plan to incorporate group work in the lab portion of the class as well as the time in the classroom. While the core group of students taking this course will never take another science class, it is important to convey to them the importance of engineering in everyday life and for them to gain a greater appreciation for science.

The main expectation of this thesis project was to present a finished proposed honors lab science course complete with a syllabus, curriculum, suggested course schedule, and lecture material. This is in the form of a thesis paper that was presented to the Honors College and Department of Chemical Engineering. As well as supplemental materials including all of the lecture presentations, lab procedures and text readings. Since this class is presented as an honors lab science, it was necessary to go through both the Honors and Carolina Core course approval
and accreditation processes. If timing does not permit for this full approval to take effect, at the very least we have set the course up for maximum potential for success in approval by starting the process of submitting the class. We have been in contact with the chemistry and honors departments in order to get all the approvals for this class. The necessary paperwork and accreditation is in process with the hopes of being approved for implementation for the spring 2018 semester. Another expectation was that this course will be fully approved by the department of chemical engineering by the time of the honors thesis defense. This meant that the lecture materials and textbook readings were reviewed by our thesis director Ed Gatzke as well as other department faculty as deemed necessary. As this is a group thesis project, it was expected that all team members will contribute evenly to the project and meet all set deadlines.

The breakdown of thesis work is as follows:

Kelly – all textbook writing, excel basics lab procedure, distillation lab procedure, pump analysis lab procedure

Kayla – half of all PowerPoint presentations, heat conduction lab procedure, basics of measuring lab procedure, pump analysis lab procedure

Jacob – half of all PowerPoint lectures, filtration lab procedure, fermentation lab procedure

Ed Gatzke (adviser) – contact with chemistry department, syllabus

All – topics list and basic research summary, contact with Honors College, proposal and final paper

The final expectation of this thesis project was that this course will be implemented into the University of South Carolina curriculum within the next school year (2017-2018).
Included with this thesis work is:

Course syllabus

Supplemental course text document

Lecture presentations

Laboratory procedures
ECHE 389 Beer, Booze, and Biofuels  
Chemical Engineering for Non-majors  
Summer 2017

Meeting Time: 
Online Lectures in June and July  
Online discussion available weekly, time TBA  
August 14-18, 9:00-5:00 (Lectures, testing, labs, tours)

Exam: 
Monday, August 14, 10:00-11:00

Final: 
Monday, August 21, 9:00-11:30

Instructor: 
Ed Gatzke  
Swearingen 3C05

Phone: 
(803) 777-1159

Email: 
gatzke@sc.edu (At home or work)

For instant messaging try Google Hangouts for messaging: ed.gatzke@gmail.com

Please identify yourself when you message or email me.  
Example: “This is Ed Gatzke from ECHE 389.”

Office: 
Swearingen 3C05

Office hours: 
By appointment

TA: ???

Description –

Beer, Booze, and Biofuels. (3) (Prereq: none) A qualitative introduction to fundamental scientific and engineering principles commonly applied in the chemical process industries. Specific applications considered include reactive, separation, and energy systems in the context of production of brewed products, distilled spirits, and liquid fuels. (Specifically designed for non-science and non-engineering majors.)

Goals –

1. Students will demonstrate understanding of the basic components of a chemical process.
2. Students will remember basic facts related to fermentation, separation, and energy processes.
3. Students will demonstrate the ability to convert basic unit measurements.
4. Students will demonstrate a basic ability to analyze data from a chemical process.

Students should develop a conceptual understanding of chemical process systems and how chemical process technologies relate to society. Course topics include fermentation reactions, distillation separations, and energy production.
**Specific Topics** –

Converting basic units  
Basics of chemical reactions  
Types of beers and wines  
Types of distilled spirits  
Basics of fermentation reactions  
Basic steps in the brewing process  
The concepts of force, energy, work, and power  
The general mass balance equation  
Types of energy (types of kinetic potential energy)  
Concepts of yield, specificity, and selectivity  
Basics types of chemical process unit operations  
Introductory concepts from transport phenomena  
Basics of vapor-liquid equilibrium  
Measuring experimental values  
Calculations related to density, concentration, and ideal gas  
Making excel plots to analyze data

**Textbook** –

Reading assignments will be provided for most class lectures. Ideally, students should review the topics before coming to class. Students should read the assignments before attempting homework assignments.

**Suggested Textbook** –

**Expectations** –

The workload and assignments should require up to 8 hours each week in addition to the 3 hours of class. Please let me know if assignments require more time.

Students are expected to give advance notification for scheduled absence from quizzes and exams. A doctor’s note is required for unscheduled absences from exams and quizzes. Exams and quizzes will not be made up without proper notification. Late assignments will not be accepted.

Common courtesy is expected in lectures with respect to cell phones, latecomers, and side conversations. Relevant questions and contributions are encouraged during class.

Students are encouraged to work and study in groups. Each individual must turn in distinct homework assignments. Late assignments will not be accepted. Workload for group assignments is expected to be shared among students in the group. Please notify the instructor if a group member fails to adequately contribute to group assignments.
Homework –

Homework is assigned for your benefit to reinforce concepts discussed in class and prepare you for examinations and quizzes. You may consult classmates, but do not blindly copy their solution.

Homework assignments will be graded on a coarse 0-10 grading scale with three possible grades, 0, 5, and 10 as following:

- 0 homework not turned in or mostly incorrect
- 5 solutions partially correct
- 10 solutions mostly correct

Please submit your homework at the beginning of class. Solutions will be made available, location TBA.

Use one side of 8½”x11” paper starting each problem on a new page and boxing answers. The first page should include your name and date of submission. Staple your homework in the upper left corner. Multiple page assignments that are not stabled will not be accepted.

Labs –

Laboratory exercises consist of experiments and computer laboratory experiences. Labs should be straightforward exercises and will be graded on a 0, 5, 10 scale. Group exercises will receive a grade as a group. Computer labs will be performed individually unless otherwise noted.

For experimental exercises, you will be divided into groups of 2-4. One person will be in charge of running the experiment, one person will be responsible for determining the theoretical results/calculation, and one person will be responsible for compiling and writing the report. The group should turn in one report, consisting of the following:

- A one-page executive summary of the experiment and results (5-10 sentences)
- A one-page data sheet, plot, or figure

Examinations –

Three quizzes are scheduled during the semester. One one-hour midterm exam and a final exam are scheduled.

Class Participation –

During lectures, individual or group exercises / discussion topics may be presented. Each student should hand in a written record of these exercises at the end of each class. This will be used to help gauge attendance and class participation. Students can also submit comments and suggestions as course feedback using this written record.
Grading –

Grading mistakes must be submitted for consideration in writing within a week of being returned. Papers submitted for consideration may raise or lower final grade.

Evaluation breakdown

- 3 Quizzes 10% each
- 1 Exam 15%
- 1 Cumulative Final Exam 20%
- Homework / Labs / Projects 30%
- Class participation 5%

The final grading scale is not fixed. Final letter grade values will be determined at the end of the semester. However, the breakdown is often close to “standard”, i.e. 90% A, > 85% B+, etc.
**Academic Integrity**
You are expected to practice the highest possible standards of academic integrity. Any deviation from this expectation will result in a minimum academic penalty of your failing the assignment, and will result in additional disciplinary measures including referring you to the Office of Academic Integrity. Violations of the University's Honor Code include, but are not limited to using another student's work, cheating during an exam or quiz, and any other form of academic misrepresentation. For more information, please see the Honor Code. **Remember that the first tenet of the Carolinian Creed is, "I will practice personal and academic integrity."**

**Accommodating Disabilities**
Reasonable accommodations are available for students with a documented disability. If you have a disability and may need accommodations to fully participate in this class, contact the Office of Student Disability Services: 777-6142, TDD 777-6744, email sasds@mailbox.sc.edu, or stop by LeConte College Room 112A. All accommodations must be approved through the Office of Student Disability Services.

**Amending the Syllabus**
Amendments and changes to the syllabus, including evaluation and grading mechanisms, are possible. The instructor must initiate any changes. Changes to the grading and evaluation scheme must be voted on by the entire class and approved only with unanimous vote of all students present in class on the day the issue is decided. The lecture schedule and reading assignments (daily schedule) will not require a vote and may be altered at the instructor's discretion. Grading changes that unilaterally and equitably improve all students' grades will not require a vote. Once approved, amendments will be distributed in writing to all students via Blackboard.

**Assignment Submission**
Assignments are always due before class starts on the day noted. Late assignments will be accepted only in cases of emergency.

**Attendance Policy**
When you miss class, you miss important information. If you are absent, you are responsible for learning material covered in class. If you are absent when an assignment is due, you must have submitted the assignment prior to the due date to receive credit. If you miss more than 10% of the classes, whether excused or unexcused, your grade will be dropped one letter grade.

**Diversity**
In addition to scheduling exams, I have attempted to avoid conflicts with major religious holidays. If, however, I have inadvertently scheduled an exam or major deadline that creates a conflict with your religious observances, please let me know as soon as possible so that we can make other arrangements.

**Classroom Behavior**
All cell phones and pagers are to be turned off or silenced during class (not on vibrate). All cell phones are to be put away out of view during class; there is no text messaging,
web browsing, etc., during class. There will be no eating during class time. Failure to adhere to these classroom rules may result in your being dismissed from class and/or an academic penalty.

**Final Examination**
Students who are absent from any final examination will be given the grade of F on the course if they have not offered an excuse acceptable to the instructor. Re-examinations for the purpose of removing an F or raising a grade are not permitted. If the absence is excused, students will be assigned a grade of I, and may complete the course under the conditions specified by the instructor in the "Assignment of Incomplete Grade" form. A student with excused absence from a final examination in one semester may take the deferred examination at the next regular examination period provided the examination is taken at the convenience of the professor. The examination must be taken within one calendar year from the time the absence was incurred. Deferred examinations will be granted only in case of absence certified as unavoidable because of documented illness or other cause, rendering attendance at final examinations impossible.

**Midterm Exam**
Makeup exams will be allowed only with pre-approval of the instructor or with an acceptable, documented reason. Acceptable reasons for makeup exams include severe illness, family emergencies or other unavoidable events including dangerous weather conditions and car accidents. Exam format for makeup exams may be different than the original exam and will likely utilize a short answer format. An oral examination may also be utilized if deemed appropriate by the instructor.
Course Laboratory Experiences

1. Introduction to Excel using formulas and cell referencing
2. Plotting data in Excel
3. Pumps experiment
4. Heat conduction and convection experiment
5. Filtration experiment
6. Distillation experiment
7. Fermentation experiment
8. Brewery tour
9. Distillery tour
10. Biofuels process tour
<table>
<thead>
<tr>
<th>Topic</th>
<th>Reference?</th>
<th>Lecture</th>
<th>Summary statement or example question to demonstrate level of detail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wine and beer vs spirits</td>
<td></td>
<td>110</td>
<td>Wine and beer are fermented. Higher alcohol content drinks are achieved using distillation.</td>
</tr>
<tr>
<td>Wine basics</td>
<td></td>
<td>110</td>
<td>Wine is made from fermented grapes where yeast convert natural sugars to alcohol anaerobically.</td>
</tr>
<tr>
<td>Wine history</td>
<td></td>
<td>110</td>
<td>Earliest evidence of wine is in Caucasuses from 8000 years ago.</td>
</tr>
<tr>
<td>Red wine vs white wine</td>
<td></td>
<td>110</td>
<td>White wine is made from filtered grape juice, while red wine is fermented pulp including grape skins.</td>
</tr>
<tr>
<td>Champagne</td>
<td></td>
<td>110</td>
<td>Champagne is made using a second fermentation, allowing the CO2 to stay in the wine.</td>
</tr>
<tr>
<td>Sake</td>
<td></td>
<td>110</td>
<td>Sake is wine made from rice with the bran removed through a brewing process.</td>
</tr>
<tr>
<td>History of moonshine</td>
<td></td>
<td>110</td>
<td>Appalachian mountain roads were terrible so it was more valuable to transport whiskey than corn.</td>
</tr>
<tr>
<td>18th amendment</td>
<td></td>
<td>110</td>
<td>The 18th amendment took effect in 1920, starting prohibition.</td>
</tr>
<tr>
<td>21st amendment</td>
<td></td>
<td>110</td>
<td>The 21st amendment repealed prohibition in 1933.</td>
</tr>
<tr>
<td>Brandy</td>
<td><a href="http://www.madehow.com/Volume-7/Brandy.html">http://www.madehow.com/Volume-7/Brandy.html</a></td>
<td>110</td>
<td>Brandy is an alcoholic beverage that is made from distilling wine (or any other sugar containing liquid). The fruit juice must be allowed to ferment and then the solution is boiled off so that the alcohol evaporates along with the fruit aromas and the water and bitterness is left behind as waster.</td>
</tr>
<tr>
<td>Whiskey</td>
<td><a href="http://whiskyadvocate.com/whisky-101/">http://whiskyadvocate.com/whisky-101/</a></td>
<td>110</td>
<td>Whiskey is an alcoholic beverage distilled from fermented grain mash. After the distillation process it is then aged in oak barrels to add flavor.</td>
</tr>
<tr>
<td>Rye whiskey</td>
<td><a href="http://www.liquor.com/spirit/rye-whiskey/">http://www.liquor.com/spirit/rye-whiskey/</a></td>
<td>110</td>
<td>Rye Whiskey is a type of whiskey that contains at least 51% rye grass and it must also be aged in new, charred, American-oak barrels.</td>
</tr>
<tr>
<td>Irish Whiskey</td>
<td><a href="http://whiskyadvocate.com/2010/03/12/what-is-irish-whiskey/">http://whiskyadvocate.com/2010/03/12/what-is-irish-whiskey/</a></td>
<td>110</td>
<td>Irish Whiskey is whiskey that is distilled in Ireland and must be aged a minimum of three years in oak barrels.</td>
</tr>
<tr>
<td>Canadian Whiskey</td>
<td><a href="http://www.liquor.com/spirit/canadian-whisky/">http://www.liquor.com/spirit/canadian-whisky/</a></td>
<td>110</td>
<td>Canadian Whiskey is whiskey that is distilled and aged in Canada. It is typically made of rye but other grains are often used.</td>
</tr>
<tr>
<td>Rum</td>
<td><a href="http://www.ministryoffruit.com/article_how_rum_is_made.php">http://www.ministryoffruit.com/article_how_rum_is_made.php</a></td>
<td>110</td>
<td>Rum is made from crushed sugar cane stalks. The sugar cane juice is fermented and then distilled. For certain rums, the sugar cane juice is cooked into a syrup or molasses.</td>
</tr>
<tr>
<td>Tequila</td>
<td><a href="https://www.diffordsguide.com/encyclopedia/991/beans-tequila-how-is-tequila-made-and-what-from">https://www.diffordsguide.com/encyclopedia/991/beans-tequila-how-is-tequila-made-and-what-from</a></td>
<td>110</td>
<td>Tequila is a cooked and distilled spirit made from the distillation of the agave plant. Inulin (The sugars of this plant, long chain molecules) are allowed to ferment after being cooked and the solution is then distilled twice. Specialty yeast is used in most operations while some simply use naturally occurring yeast.</td>
</tr>
<tr>
<td>Gin</td>
<td><a href="http://www.foodrepublic.com/2012/04/02/wha">http://www.foodrepublic.com/2012/04/02/wha</a></td>
<td>110</td>
<td>Gin is a neutral grain spirit that is re-distilled with botanicals,</td>
</tr>
</tbody>
</table>
Vodka is a spirit of Russian origin. It is typically made from any type of grains, wheat, rye, barley, or potatoes. The starches and sugars of the grains are allowed to ferment and then it is distilled multiple times through activated charcoal.

Reinheitsgebot in 1516 Germany specified only water, barley, and hops could be used in making beer. Yeast was unknown at the time.

Methanol, ethanol, butanol, propanol are types of alcohol, they all differ based on molecular content ie their carbon content.

Ethanol disrupts a variety of biochemical reactions in the brain and other organs. Sleep and long-term memory formation can be adversely affected.

Lagers have a long fermentation time at colder temperatures (25-50F). They ferment for months with bottom fermenting yeast and can be stored for longer than ales. Examples are plisners, bocks and dunkels.

Ales have a much shorter fermentation process with top-fermenting yeast which is typically done at room temperature (60-75F) for a few weeks. Ales include pale ales, IPA, stouts, porters, amber ales.

Typically ale brewed with larger wheat to barley ratio of malts, its fermentation process includes esters as by-products.

Born out of the English pale ale style, but when beer was transported to India they overloaded it with hops in order to preserve the beer on the long voyage.

Ale brewed with "pale" malts (lightly roasted)

Ale brewed with amber malts or crystal malts

Dark ale with hops and brown malts. Differs from a stout in that it does not contain a roasted barley flavor.

Cider is more similar to champagne than beer. It is made with pressed apples that are fermented with a longer strand of yeast, not the same as beer yeast.

Champagne is fermented twice. The second fermentation produces the carbon dioxide which causes the bubbles.

Green grape used to produce white wine. Originated in the Burgundy wine region of France but is now grown everywhere.

White wine grape. “Pinot” means “pine cone”.

Red wine grape. Originated in the Burgundy Region of France.

Dark blue-colored grape. Red wine.

Originates from the Muscat family of grapes. Different colors. Thought to originate with the Egyptians.

Red wine grape. Grown in many different climates from Canada to Lebanon. Originated in southwestern France.

The basic winemaking process is the same in all regions, with fermentation etc. however the difference comes in the amount of time allowed to ferment as well as the temperatures and type of grape. (similarly weather it is a white or red or rose wine)

The foreshot is the first liquid from a batch still, containing the low-boiling light components (like methanol)

The thumper is a liquid filled tank that bubbles the vapors through, resulting in a second separation and higher proof alcohol

50% Alcohol by Volume (ABV) is defined as 100 proof
<table>
<thead>
<tr>
<th>PGA (Pure Grain Alcohol)</th>
<th>120</th>
<th>Pure grain alcohol is 190 proof.</th>
</tr>
</thead>
<tbody>
<tr>
<td>100% alcohol in air</td>
<td>120</td>
<td>Pure 200 proof alcohol will absorb water from humid air</td>
</tr>
<tr>
<td>Making beer process</td>
<td>120</td>
<td>Malting, kilning, milling, mashing, fermenting, bottling are the six basic steps in beer making.</td>
</tr>
<tr>
<td>Wort</td>
<td>120</td>
<td>Wort is the liquid before fermentation takes place.</td>
</tr>
<tr>
<td>Malting</td>
<td>120</td>
<td>The main goal of malting is to isolate the enzymes needed for brewing. This is done by heating, drying, and cracking the malts</td>
</tr>
<tr>
<td>Kilning</td>
<td>120</td>
<td>Kilning is the final stage of traditional malting. The goal is to significantly decrease the malt's moisture content</td>
</tr>
<tr>
<td>Milling</td>
<td>120</td>
<td>Milling is the process where the outer layer (husk) of the grain is removed via crushing. The inner layer (endosperm) is broken up to allow maximum enzyme harvest via the mashing liquid.</td>
</tr>
<tr>
<td>Mashing</td>
<td>120</td>
<td>In mashing, the malt is placed in a hot but not boiling vat of water to extract the enzymes and sugars to be used in brewing. This process creates the wort.</td>
</tr>
<tr>
<td>Fermenting</td>
<td>120</td>
<td>Fermentations take place after the wort has been boiled and hops added for flavor when the wort is placed in vessels and yeast is added. This is done at a variety of different temperatures and types depending on the type of beer. The yeast eats up sugars from the wort and produces CO2 and alcohol as products.</td>
</tr>
<tr>
<td>Yeast produce CO2 to leaven bread. Micro-organisms can produce lactic acid through fermentation to make yogurt and sauerkraut. Cheese, olives, and vinegar can be produced or stored due to fermentation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit conversion, cm to m to mm</td>
<td>130</td>
<td>Convert xx mm to cm and m</td>
</tr>
<tr>
<td>Unit conversion, l to ml to gallon</td>
<td>130</td>
<td>Convert xx ml to L and gallons</td>
</tr>
<tr>
<td>Unit conversion, g to mg to kg to lb</td>
<td>130</td>
<td>Convert xx g to kg and mg and lb (metric to us units)</td>
</tr>
<tr>
<td>Pressure scale conversions</td>
<td>130</td>
<td>Convert xx psig to atm to Pa etc.</td>
</tr>
<tr>
<td>C to F Temperature scale conversions</td>
<td>130</td>
<td>deg C = 5/9 (deg F - 32) deg F = 32 + deg C * 9/5</td>
</tr>
<tr>
<td>Significant Figures</td>
<td>130</td>
<td>What is the number of sig figs needed for addition, multiplication, etc. work number problems</td>
</tr>
<tr>
<td>Volume</td>
<td>130</td>
<td>use in cheme problems, how to calculate given dimensions, various shapes, volume is in 3 dimensions and is typically units of length^3 or fluid measurements of gal, fl oz, etc.</td>
</tr>
<tr>
<td>Area</td>
<td>130</td>
<td>use in cheme problems, how to calculate given dimensions, various shapes, surface vs cross sectional, typical units are length^2</td>
</tr>
<tr>
<td>Surface area</td>
<td>130</td>
<td>Calculate the surface area of basic shapes such as cubes, spheres, cones given specific equations</td>
</tr>
<tr>
<td>Pressure</td>
<td>140</td>
<td>Pressure is force per area.</td>
</tr>
<tr>
<td>Atmospheric pressure</td>
<td>140</td>
<td>Atmospheric pressure is 14.7 pounds per square inch (PSIA)</td>
</tr>
<tr>
<td>Absolute vs gauge scales</td>
<td>140</td>
<td>Gauge pressure reads 0 at 1 atmosphere absolute pressure</td>
</tr>
<tr>
<td>Weight vs mass</td>
<td>140</td>
<td>All objects have mass. Any object in a gravitational field has weight.</td>
</tr>
<tr>
<td>Volume vs flow rate</td>
<td>140</td>
<td>A vessel has units of volume but a pipe or pump has units of flow, volume / time</td>
</tr>
<tr>
<td>Density</td>
<td>140</td>
<td>Density is defined as mass / volume. Water at standard conditions has a density of 1 g/ml.</td>
</tr>
<tr>
<td>Specific gravity</td>
<td>140</td>
<td>Specific gravity is the ratio of the density of the substance in question to the density of pure water at STP conditions</td>
</tr>
<tr>
<td>Extensive vs intensive properties</td>
<td>140</td>
<td>Extensive properties depend on the size (V, mass, surface area, etc.), intensive properties are size independent (density, pressure,</td>
</tr>
<tr>
<td><strong>STP</strong></td>
<td>140</td>
<td>Standard Temperature and Pressure is typically 273K (0 C) and 1 atm (14.7 psia)</td>
</tr>
<tr>
<td>-------------------------</td>
<td>-----</td>
<td>--------------------------------------------------------------------------------</td>
</tr>
<tr>
<td><strong>densitometer</strong></td>
<td>150</td>
<td>A device used to measure the density of a material. Will be used to measure the density in the plate and frame lab</td>
</tr>
<tr>
<td><strong>Thermocouples</strong></td>
<td>150</td>
<td>In a thermocouple, two different metals joined produce a measurable voltage that changes with temperature.</td>
</tr>
<tr>
<td><strong>CNG vehicles, CNG and the environment</strong></td>
<td>160</td>
<td>Compressed Natural Gas can be used as a fuel for internal combustion engines.</td>
</tr>
<tr>
<td><strong>CNG to syn gas to polymers / liquid fuels</strong></td>
<td>160</td>
<td>Syngas contains hydrogen and carbon monoxide. It can be produced from methane, coal, or biomass. It can be used to make ammonia, methanol, or many other chemicals.</td>
</tr>
<tr>
<td><strong>Atoms and molecules</strong></td>
<td>210</td>
<td>Molecules are made up of atoms, the basic unit of chemical matter.</td>
</tr>
<tr>
<td><strong>Scientific method</strong></td>
<td>210</td>
<td>Systematic observation, measurement, and experiment for formulation, testing, and modification of hypotheses.</td>
</tr>
<tr>
<td><strong>Periodic Table</strong></td>
<td>210</td>
<td>Basics of how to read the periodic table, locate specific elements, numbering, etc.</td>
</tr>
<tr>
<td><strong>Calculating the molecular weight of a molecule</strong></td>
<td>220</td>
<td>What is the molecular weight of xx? - use the periodic table and identify the molecular weight of each individual element and add them up</td>
</tr>
<tr>
<td><strong>One mole of material</strong></td>
<td>220</td>
<td>One mole of a material is 6.02x10^23 molecules</td>
</tr>
<tr>
<td><strong>Calculating moles of material from mass</strong></td>
<td>220</td>
<td>How many moles are in xxx g of yy? Divide the mass of the compound (g) by the molecular weight of the compound (g/mol) to get moles</td>
</tr>
<tr>
<td><strong>Sugar molecule molecular formula</strong></td>
<td>220</td>
<td>The general formula for sugar molecules is C6H12O6</td>
</tr>
<tr>
<td><strong>Stoichiometry</strong></td>
<td>220</td>
<td>Stoichiometry is used to balance chemical equations so that the number of reactant atoms equals the number of product atoms.</td>
</tr>
<tr>
<td><strong>Stoichiometric ratio</strong></td>
<td>220</td>
<td>A stoichiometric ratio of 1.0 means all the reactants for a reaction are present in adequate amounts.</td>
</tr>
<tr>
<td><strong>Balancing chemical equations</strong></td>
<td>220</td>
<td>To balance a chemical reaction, all atomic elements must be in equal parts on both sides of the chemical reaction equation</td>
</tr>
<tr>
<td><strong>Liquids, solids, and gases (phases of matter)</strong></td>
<td>230</td>
<td>What are the different phases of matter and how do chemicals move to each</td>
</tr>
<tr>
<td><strong>Specific phase charts</strong></td>
<td>230</td>
<td>Read the phase chart graph: compressed liquid, critical point, superheated vapor, saturated liquid line</td>
</tr>
<tr>
<td><strong>Basics of pH</strong></td>
<td>230</td>
<td>a scale that demonstrates the compounds H+ levels (acidity), the scale ranges from 1-14 with each number being 10 times less acidic than the previous, 1-6 are acidic, 8-14 are basic</td>
</tr>
<tr>
<td><strong>Catalyst definition</strong></td>
<td>230</td>
<td>A catalyst speeds up a chemical reaction without itself being consumed in the reaction.</td>
</tr>
<tr>
<td><strong>Activation Energy</strong></td>
<td>230</td>
<td>The minimum quantity of energy needed to overcome the barrier to begin a chemical reaction (Ea)</td>
</tr>
<tr>
<td><strong>Equilibrium</strong></td>
<td>230</td>
<td>The forward and reverse reactions are occurring at the same rate and the reaction is at a stable, balanced point. Work some problems with this using K. K is defined as [products]/[reactants]</td>
</tr>
<tr>
<td><strong>limiting reactant</strong></td>
<td>230</td>
<td>stoichiometrically limited reactant determines the rate and extent of reaction, how to calculate which reactant is limiting</td>
</tr>
<tr>
<td><strong>Fermentation for ATP energy production</strong></td>
<td>240</td>
<td>Fermentation takes place when oxygen is not available, becoming primary means of ATP (energy) production in a cell.</td>
</tr>
<tr>
<td>Topic</td>
<td>Page</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------------------------------------------------------</td>
<td>------</td>
<td>------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Aerobic vs. anaerobic</td>
<td>240</td>
<td>Aerobic process uses air, anaerobic does not</td>
</tr>
<tr>
<td>Cellular respiration</td>
<td>240</td>
<td>Cells prefer to extract energy from glucose using oxygen</td>
</tr>
<tr>
<td>Fermentation and O2</td>
<td>240</td>
<td>Fermentation is an anaerobic process, meaning oxygen is limited during the reaction</td>
</tr>
<tr>
<td>Small hydrocarbons</td>
<td>240</td>
<td>Methane, ethane, propane, and butane are small hydrocarbon chains (hydrocarbons consist of only hydrogen and carbon molecules)</td>
</tr>
<tr>
<td>Concept of energy and the joule</td>
<td>300</td>
<td>A joule of energy is 1 kg/ms². In Earth's 9.8 m/s² gravity, a 102 g object 1 m above ground has 1 joule of potential energy</td>
</tr>
<tr>
<td>General mass balance equation (conservation eq)</td>
<td>300</td>
<td>Accumulation rate = In - Out + Created - Destroyed</td>
</tr>
<tr>
<td>Energy content of ethanol vs gasoline by volume</td>
<td>300</td>
<td>1.5 gallons of pure ethanol has the same heating value as 1.0 gallons of gasoline.</td>
</tr>
<tr>
<td>Energy content of liquefied natural gas vs gasoline by volume</td>
<td>300</td>
<td>1.54 gallons of liquefied natural gas has the same heating value as 1.0 gallons of gasoline.</td>
</tr>
<tr>
<td>Energy content of methanol vs gasoline by volume</td>
<td>300</td>
<td>2.0 gallons of methanol has the same heating value as 1.0 gallons of gasoline.</td>
</tr>
<tr>
<td>Energy content of hydrogen vs gasoline</td>
<td>300</td>
<td>1 kg of hydrogen has the same heating value as 1.0 gallons of gasoline.</td>
</tr>
<tr>
<td>Ideal gas law</td>
<td>300</td>
<td>PV=nRT, a gas is ideal under certain standard conditions such as no intermolecular forces, all internal energy is kinetic and changes in energy result in changes in temperature</td>
</tr>
<tr>
<td>Energy and Power</td>
<td>300</td>
<td>Joules measure energy. One joule per second generated / used is a Watt.</td>
</tr>
<tr>
<td>Work</td>
<td>300</td>
<td>W=P dV, E=q+w, work of expansion</td>
</tr>
<tr>
<td>Power</td>
<td>300</td>
<td>P = W/t. SI units are W. Power is defined as the rate of doing work. The amount of energy consumed per unit time.</td>
</tr>
<tr>
<td>latent heating effects</td>
<td>300</td>
<td>vaporization, fusion/melting, sublimation</td>
</tr>
<tr>
<td>Potential and Kinetic Energy</td>
<td>300</td>
<td>Kinetic energy is energy in motion, potential energy is energy that can do work</td>
</tr>
<tr>
<td>Types of potential energy</td>
<td>300</td>
<td>Types of potential energy include gravitational potential, chemical potential, elastic (spring) potential, and electric potential</td>
</tr>
<tr>
<td>CO2 emitted for same amount of energy released</td>
<td>300</td>
<td>Amount of CO2 emitted for same amount of energy released: Coal &gt; Diesel &gt; Gas &gt; Propane &gt; Natural Gas (Methane)</td>
</tr>
<tr>
<td>Heat of reaction</td>
<td>400</td>
<td>Unit of measurement to calculate the change in enthalpy of a reaction at constant pressure (way to measure the amount of energy released or produced in a reaction)</td>
</tr>
<tr>
<td>Process Block Diagrams</td>
<td>400</td>
<td>Draw a process diagram from a general description</td>
</tr>
<tr>
<td>Engineering design method</td>
<td>400</td>
<td>Define the problem, do research, specify requirements, develop solutions, choose the best solution, build a prototype, test and redesign</td>
</tr>
<tr>
<td>Engineering ethics basics</td>
<td>400</td>
<td>Brief introduction to common cases and what engineering ethics entails.</td>
</tr>
<tr>
<td>Engineering ethics case studies</td>
<td>400</td>
<td>Studying specific engineering failure cases to determine possible areas of improvement for the future or generate awareness of previous mistakes not to be repeated</td>
</tr>
<tr>
<td>Non ideal mixing</td>
<td>400</td>
<td>Mixing 100 ml of water with 100 ml 200 proof ethanol results in less than 200 ml of the mixture</td>
</tr>
<tr>
<td>Excel plotting lines</td>
<td>400</td>
<td>how to generate plots of empirical data in excel... putting stuff in columns and rows and the graphing function, how to select data, etc.</td>
</tr>
<tr>
<td>Excel equations and cell referencing</td>
<td>400</td>
<td>basic excel shortcuts and equation generation, how to click and reference cells in the equation embedded in other cells</td>
</tr>
<tr>
<td>Topic</td>
<td>Page</td>
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<tr>
<td>--------------------------------------------</td>
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<tr>
<td>least squares method of regression</td>
<td>400</td>
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</tr>
<tr>
<td>R squared values are a measure of goodness of fit, ranging from 0 (bad) to 1.0 (good)</td>
<td></td>
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<tr>
<td>Linear form for equations</td>
<td>400</td>
<td></td>
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<tr>
<td>Demonstrate converting a logarithmic equation or higher order polynomial into a straight line</td>
<td></td>
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<tr>
<td>Lab Safety Day</td>
<td>400</td>
<td></td>
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<tr>
<td>Lab safety expert presents</td>
<td></td>
<td></td>
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<tr>
<td>Efficiency</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>actual/theoretical for a given situation, example: actual percent yield/theo, can also be used in energy generation</td>
<td></td>
<td></td>
</tr>
<tr>
<td>flow vs mass flow rate vs velocity</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Q = velocity x area, velocity is m/s, molar flow rate is mol/time, mass flow rate is mass/time, Q = mass flow rate/density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>mole/mass fraction</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>mole fractions are moles of x / total moles, mass fractions are mass of x / total mass, these two numbers are not interchangeable but can be used along with other information to calculate each other</td>
<td></td>
<td></td>
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<tr>
<td>conversion</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>amount of reactant used/reactant fed in, solving word problems</td>
<td></td>
<td></td>
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<tr>
<td>yield</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>amount of product produced/total possible amount to produce, solving word problems</td>
<td></td>
<td></td>
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<tr>
<td>purity</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>mass of desired product/total mass of products, solving word problems</td>
<td></td>
<td></td>
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<tr>
<td>selectivity</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>amount of reactant consumed in rxn 1 / total amount consumed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>exponential growth</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Exponential growth is a function whose rate increase more rapidly as time goes on. What is the shape of an exponential function? Yeast growth in fermentation is an exponential function</td>
<td></td>
<td></td>
</tr>
<tr>
<td>interpolation</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>How to interpolate data in steam tables or any data at various temperatures and pressures when the exact value needed is not provided</td>
<td></td>
<td></td>
</tr>
<tr>
<td>degree of freedom analysis</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Ndf = # unknowns - # independent eqs, if ndf = 0 we can solve the problem, if ndf &gt; 0 then the problem is underspecified, if ndf &lt; 0 then the problem is over specified</td>
<td></td>
<td></td>
</tr>
<tr>
<td>excess feed</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>A reactant is deemed in excess when compared to its theoretical stoichiometric ratio with the limiting reactant. See recycle streams, why would a reactant be fed in excess? Increase equilibrium or selectivity of a certain product</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dew point and boiling point calcs</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>mixtures and pure components, use mass/mol fractions to calculate Tbp and Tdp of mixtures, use Psat calcs to find the BP and DP of components</td>
<td></td>
<td></td>
</tr>
<tr>
<td>types of systems</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>explore the differences between closed, open and isolated systems</td>
<td></td>
<td></td>
</tr>
<tr>
<td>turbines</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Example: windmill. Turbines are machines designed to capture energy from a fluid so it can be put to use.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>rigid vs non-rigid systems</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>U involved in non-rigid, rigid is clearly defined and unchangeable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unit Processes</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Introduction to various unit processes like distillation column, mixer, etc.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mixer</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Used to combine two or more process streams together</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vessels</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>A container use to store gases or liquids in a process.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Compressors</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>A mechanical device used to increase the pressure of a gas by reducing its volume.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>speed vs velocity</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Velocity is different than speed. Velocity is a vector quantity, including magnitude (speed) and direction.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recycle streams</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Recycle streams help to reduce the amount of feed stock needed by recycling back unreacted reactants. They are beneficial in cutting costs and also help to keep the stoichiometric ratio to the reactor constant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>still</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>What is a Still and why is it used? (distillation process) A still is an apparatus used to distill liquid mixtures by heating to selectively boil and then cooling to condense the vapor.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>plate and frame filtration</td>
<td>400</td>
<td></td>
</tr>
<tr>
<td>Laboratory scale and in beer production- separation process used specifically for solid/liquid systems. The driving force is pressure generated from a slurry pump. Solid cakes build up on filter paper as</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
the liquid is able to pass through each porous plate.

<p>| State vs path functions | Extent of Reaction | Chemical reactions | Fermentation reaction | Biodiesel production | Biogas (natural gas) from waste process | Combustion Reactions | Lean vs. Rich | Runaway reactions | reversible vs irreversible reactions | henry's law | Inerts | VLE basics | Thermodynamic efficiency | Thermo Laws | EOS | Steam Tables | Enthalpy | Entropy | Azeotropes | Humidity, dry bulb wet bulb | Vapor Pressure Calculations | P-V diagrams | P-T diagrams | T-V diagrams | Refrigeration cycle | Internal combustion engine | Isothermal stuff |
|-------------------------|-------------------|-------------------|----------------------|----------------------|---------------------------------------|----------------------|--------------|------------------|-----------------------------|-------------|---------|----------|--------------------------|---------------|------|-------------|----------|--------|------------|--------------------------|--------------------------|----------------|--------------|------------|-------------|--------------------------|---------------------------|-------|
| 400                     | 500               | 500               | 500                  | 500                  | 500                                  | 500                  | 500          | 500              | 500                         | 400         | 500     | 600       | 600                      | 600           | 600  | 600         | 600      | 600    | 600        | 600                      | 600                       | 600  | 600         | 600       | 600    | 600       | 600                      | 600                       | 600  | 600         | 600       | 600    | 600       |
| temperature is a state function and does not depend on how you got there just the state of the system currently | The degree to which the reaction reaches completion or full conversion of reactants to products (units: moles) | Chemical reactions rearrange the structure of molecules | Fermentation reactions in yeast can produce alcohol from sugars metabolically | Biodiesel is produced using transesterification and esterification, where vegetable or animal fats / oils are reacted with methanol or ethanol. | Anaerobic digestion of sewage or plant waste to make natural gas (methane) | Combustion reactions burn fuels with oxygen to release energy | For combustion reactions, a running lean means less oxygen than the ideal stoichiometric ratio, while rich means too much. | A process by which an exothermic reaction goes out of control and often results in an explosion. | Deals with equilibrium, when a reaction can return to its original state or not, different varying degrees of reversibility. | Inerts have no effect on the actual kinetics or basics of a chemical reaction but can be used as a temperature or pressure check as they alter the overall volume of the process | Vapor–Liquid Equilibrium (VLE) describes the distribution of a chemical species between the gas phase and a liquid phase | Thermal efficiency is a measure of how much energy is actually converted to usable work | law of conservation of energy, entropy of an isolated system always increases | generic EOS - ideal gas law and its evolution to EOS such as soave and PR | how to use and steam table and what info is present, when to use it, which to use-- i.e. sat liq, superheated, etc. | U+PV, internal energy of the system plus pressure and volume, | degree of randomness in the system, spontaneity of the system, nature tends towards maximum entropy | Azeotrope is a mixture where the vapor from boiling has the same composition as the liquid | Calculate dry bulb/wet bulb temperatures from wet/dry value, Calculate % humidity, relative humidity, etc. Reading data off of the chart | use of the antione eq, cox charts and clausius clapeyron equation | What is a P-V diagram and when is it used? | What is a P-T diagram and when is it used? | What is a T-V diagram and when is it used? | Probably too advanced, Maybe not? | Label gas/liquid hot/warm lowP/highP on diagram | <a href="http://www.howtechnologywork.com/wp-content/uploads/2015/05/Refrigeration-Cycle1.jpg">http://www.howtechnologywork.com/wp-content/uploads/2015/05/Refrigeration-Cycle1.jpg</a> | Internal combustion engines have controlled combustion reactions to drive a piston to create mechanical work | An isothermal process does not change temperature |</p>
<table>
<thead>
<tr>
<th>Topic</th>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Isobaric stuff</td>
<td>600</td>
<td>An isobaric process does not change pressure</td>
</tr>
<tr>
<td>Isentropic</td>
<td>600</td>
<td>An isentropic process does not change entropy, it is adiabatic and reversible</td>
</tr>
<tr>
<td>Adiabatic</td>
<td>600</td>
<td>An adiabatic process does not allow energy to enter or leave the system</td>
</tr>
<tr>
<td>Exothermic vs endothermic</td>
<td>600</td>
<td>Exothermic reactions give off energy while exothermic reactions take in energy</td>
</tr>
<tr>
<td>Introduction to non-ideal gases</td>
<td>600</td>
<td>EOS, etc, how to proceed</td>
</tr>
<tr>
<td>gas-liquid phase reactions</td>
<td>Too much</td>
<td>how to solve gas problems on a partial pressure basis instead of a mole fraction, partial pressure can be used to determine concentration of each gas</td>
</tr>
<tr>
<td>partial pressure calcs</td>
<td>Too much</td>
<td>one pure component, use raoult's law and Psat calculations to solve a VLE system</td>
</tr>
<tr>
<td>raoult's law</td>
<td>Too much</td>
<td>how to solve gas problems on a partial pressure basis instead of a mole fraction, partial pressure can be used to determine concentration of each gas</td>
</tr>
<tr>
<td>multicomponent gas-liquid systems</td>
<td>Too advanced? - it was covered in 300</td>
<td>heat of formation, how can we apply hess's law to determine heat of formation of chemical reactions, add all heat of formations together to get the overall heat of formation for a new chemical reaction</td>
</tr>
<tr>
<td>Hess's law</td>
<td>??</td>
<td></td>
</tr>
<tr>
<td>Diesel cycle</td>
<td>600</td>
<td>Label the steps in a diesel cycle</td>
</tr>
<tr>
<td>Otto cycle</td>
<td>600</td>
<td>Label steps in the Otto cycle</td>
</tr>
<tr>
<td>Batch distillation</td>
<td>700</td>
<td></td>
</tr>
<tr>
<td>Distillation columns</td>
<td>700</td>
<td>components of a distillation column and how they work on a basic level (no specific problems)</td>
</tr>
<tr>
<td>Distillation and relation to petrochemical / air sepn</td>
<td>700</td>
<td>Differences in boiling points can be used to separate liquids, including alcohols, oil/gas/asphalt/petrochemicals, and even liquefied air.</td>
</tr>
<tr>
<td>Types of separations</td>
<td>700</td>
<td>distillation, adsorption, packed bed, stripping, extraction, membrane</td>
</tr>
<tr>
<td>Fluid dynamics</td>
<td>Too advanced?</td>
<td>Bernoulli Equation, fluids in motion, continuity equations</td>
</tr>
<tr>
<td>Fluid statics</td>
<td>800</td>
<td>Hydrostatic forces on plane surfaces, manometers, ( P = \text{density} \times g \times \text{d} ), ( F = PA ), vectors? too advanced?</td>
</tr>
<tr>
<td>Control volume</td>
<td>Too much</td>
<td>when we use a control volume, no expansion work can be done on the system</td>
</tr>
<tr>
<td>Viscosity</td>
<td>800</td>
<td>The measure of a fluid's resistance to flow. Ex: molasses=high; water=medium; gas=low.</td>
</tr>
<tr>
<td>Drag</td>
<td>??</td>
<td>Like on an airplane, fluid drag?</td>
</tr>
<tr>
<td>Laminar vs. turbulent flows</td>
<td>800</td>
<td>Flow in a pipe. Laminar flow is orderly and occurs at low speeds. Turbulent flow is unpredictable and happens at high speeds.</td>
</tr>
<tr>
<td>Dimensionless numbers</td>
<td>Bubbles in Guinness??</td>
<td>A quantity that how no physical dimensions. Some examples include Reynolds and Biot numbers.</td>
</tr>
<tr>
<td>shearing stress and strain</td>
<td>Reynold's number? - Biot?</td>
<td>Newtonian fluids are the simplest models for fluid flow as their forces for stress and strain are uniform throughout(viscosity is only dependent on temperature) examples include water, honey, organic solvents, nonnewtonian fluids viscosity is dependent on shear rate</td>
</tr>
<tr>
<td>Newtonian fluids vs non Newtonian</td>
<td>Too much ??</td>
<td>Newtonian fluids are the simplest models for fluid flow as their forces for stress and strain are uniform throughout(viscosity is only dependent on temperature) examples include water, honey, organic solvents, nonnewtonian fluids viscosity is dependent on shear rate</td>
</tr>
<tr>
<td>Reynolds's number</td>
<td>800</td>
<td>( Re = \text{density} \times L \times u / \text{viscosity} )</td>
</tr>
<tr>
<td>hagen-poiseuille</td>
<td>many be too advanced</td>
<td>Newtonian fluids are the simplest models for fluid flow as their forces for stress and strain are uniform throughout(viscosity is only dependent on temperature) examples include water, honey, organic solvents, nonnewtonian fluids viscosity is dependent on shear rate</td>
</tr>
<tr>
<td>Topic</td>
<td>Notes</td>
<td>Level</td>
</tr>
<tr>
<td>-------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
<td>-------</td>
</tr>
<tr>
<td>Naiver-Stokes Equation</td>
<td>many be too advanced</td>
<td>800</td>
</tr>
<tr>
<td>friction factor</td>
<td>A friction factor can be used to estimate the pressure drop for flow in a pipe of a given surface roughness. Use of moody chart?</td>
<td>800</td>
</tr>
<tr>
<td>Conduction and Convection definitions</td>
<td>Conduction is heat transfer in a solid while convection is heat transfer at a solid / liquid (or gas) interface</td>
<td>900</td>
</tr>
<tr>
<td>Heat exchangers</td>
<td>Heat exchangers allow two process streams to exchange energy. The hot flow gets colder and the cold flow gets hotter. Liquid-air heat exchangers are often called radiators. Liquid-liquid heat exchangers are often run in countercurrent fashion.</td>
<td>900</td>
</tr>
<tr>
<td>Brewing process, general</td>
<td>Brewing first heats a wet starch (such as barley) then proceeds with fermentation to produce alcohol</td>
<td>1000</td>
</tr>
<tr>
<td>E85 gas</td>
<td>E85 flex fuel is a mix of gasoline and ethanol containing 51-85% ethanol.</td>
<td>1000</td>
</tr>
<tr>
<td>Flex Fuel Vehicle</td>
<td>A Flex Fuel Vehicle requires different engine timing and some specialized ethanol resistant parts / coatings.</td>
<td>1000</td>
</tr>
<tr>
<td>Pumps</td>
<td>Centrifugal pumps use an impeller to turn rotational kinetic energy into hydrodynamic energy, resulting in increased pressure and/or fluid flow.</td>
<td>1000</td>
</tr>
<tr>
<td>Whisky production process</td>
<td>What are the basic steps in the whiskey distillation process?</td>
<td>1000</td>
</tr>
<tr>
<td>Steady-state vs transient / dynamic</td>
<td>Steady state means that the variables that define a system do not change with time. Recently observed behavior will continue to be so. Transient on the other hand changes with time</td>
<td>1000</td>
</tr>
<tr>
<td>static vs dynamic</td>
<td>A system in static is unmovong where as a dynamic system is in motion (fluids). A reaction in static equilibrium is irreversible whereas a reaction in dynamic equilibrium is reversible.</td>
<td>1000</td>
</tr>
<tr>
<td>cost comparison of different equipment options</td>
<td>Design problem with equipment specs? Build a brewery</td>
<td>1000</td>
</tr>
<tr>
<td>basic chemical engineering plant design</td>
<td>5 parts: reactor feed prep, reactor, separator feed prep, separator, reflux</td>
<td>1000</td>
</tr>
<tr>
<td>types of chemical processes</td>
<td>batch, Continuous, semi-batch (all on a very basic ECHE 300 level not kinetics level)</td>
<td>1000</td>
</tr>
</tbody>
</table>
Hello and welcome to the wonderful world of Beer, Booze, and Biofuels. Enrolling in BBB: A Intro to Chemical Engineering for non-majors is the first step to gaining a better understanding of the world and how everyday life relates to chemical engineering. This semester will be a journey that will walk through everything from the building blocks of matter to reactions to breweries and everything in between. This text will serve as a resource for the semester course work. Each topic covered during lecture is also covered in this text, often times in more detail. Use this book as a reference for any topic that needs more clarification or examples. This text is broken down into 15 different lessons that group appropriate topics together. The goal of this class is that students come away with a better understanding of what chemical engineers do and the engineering feats in everyday life. Enjoy the semester.

Lesson 1: Types of alcohol

Basics:

Alcohol in the popular sense has been present in the course of human history for centuries. There are many different types which originate from different regions all over the world. Alcohol can be created using the simple process of fermentation, where tiny biological organisms (yeast) convert their food into alcohol. The distinction for each type comes from what is being fermented as well as the subsequent processing. Wine is fermented from grapes and beer from grains using different forms of yeast. High alcohol content spirits start by fermentation as well, but after the fermentation they are distilled in order to achieve a higher alcohol content.

Alcohols in the scientific sense is a hydrocarbon molecule that contain an –OH group. Hydrocarbons are any molecule that contains only carbon and hydrogen atoms. These are
considered organic molecules. An –OH group is a group of oxygen and hydrogen molecules that is attached to a hydrocarbon. This is characteristic of all alcohols. Alcohols are named based on the carbon molecule attached to the hydroxyl group (–OH). Some common types of alcohol in both chemistry and chemical engineering are methanol (1 carbon and an -OH group), ethanol (C2H5OH or EtOH), propanol, and butanol.

![Methanol and Ethanol structures]

The type of alcohol principally produced in the production of adult beverages is ethanol. It is produced via the fermentation of sugars by yeast. Ethanol has a variety of effects on the human body depending on how much is consumed. It disrupts many of the biochemical reactions in the brain and other organs. Alcohol interferes with the brain’s communication pathways which in turn can lead to disruptions in mood, behavior, and decision making. Sleep and long term memory formation can be adversely affected in cases of long term use. Excessive drinking can also have serious effects on the heart and liver. Even casual drinking can have adverse effects on the immune system, making one an easier target for diseases.

The biological process of fermentation, is one in which small yeast organisms consume sugars and produces CO₂ and alcohol as byproducts. This process of fermentation is also used in many other food production processes. For example, yeast produces CO₂ in the leavening of bread. Similarly, microorganisms can produce lactic acid through fermentation. This way,
fermentation is used in the production of yogurt and sauerkraut. Cheese, olives, and vinegar can all be produced and/or stored long term due to fermentation.

The amount of alcohol in a given serving or bottle is typically reported in both the percent alcohol by volume as well as the proof. The percent alcohol by volume, as the name suggests is the amount of the total volume of the liquid that is alcohol. Typically the remaining liquid is water. Similarly, proof is calculated as double the percent alcohol by volume of a beverage. For example, if a whiskey is 50% ABV then its proof is 100. Pure grain alcohol is the highest possible proof. It is 190 proof or 95% ABV. 200 proof alcohol is not possible because alcohol must absorb some water from the humid air making it impossible to be 100% alcohol.

**History**

The earliest evidence of wine comes from the Caucasus Mountains around 8000 years ago. Wild grapes grew in Armenia, Georgia, Azerbaijan, all the way to Turkey. It is believed that the nomadic tribes likes the taste of these grapes and thus collected them. After a few days of storage, the sugary juice of the grapes fermented in containers, creating low concentration alcohol. The earliest known wineries originated from caves in Armenia.

The earliest beer production was in Egypt and Iran around 7000 years ago. Beer is created via the fermentation of cereals, therefore, as soon as cereals were collected, it was possible to begin the spontaneous fermentation process. Traditionally, beer brewing was a domestic process carried out by the women of the house. There is even reference to beer in the widely studied *Epic of Gilgamesh*. Brewing evolved through the years and through different societies, but remained an integral part of most ancient and medieval life. In 1516, Reinheitsgebot (Bavarian “beer purity law”) in Germany specified only water, barley, and hops
could be used in making beer. Yeast was unknown at the time in the beer making process. This would be discovered in the 18th century. Brew masters knew that there was an unknown aspect to their beer production. They knew something magic occurred in the watery mixture, turning it into alcohol. Spontaneous fermentation occurred in some regions but most breweries simply hoped that batches would not turn out spoiled. Antione van Leeuwenhoek, using the microscope, was the first to identify yeast. However, the notion that it was involved in the beer making process did not come until the late 18th and early 19th centuries. Louis Pasteur demonstrated in 1857 that without living yeast the fermentation process in beer making would not proceed. He suggested that heat could remove the impurities in beer. However, it was not until Emil Hansen that this became popularized. In 1883, Hansen was able to isolate and clone the yeast used to produce Carlsberg’s lager. The rest is history.

The history of alcohol in the United States has had many twists and turns. Beer production and brewing was largely an industry brought over by immigrants. Beer was present on the Mayflower and was brewed in most colonial towns. The flavors and colors varied by locally available ingredients. German immigrants introduced the lager to the Americas. These beers are typically stronger and made with different yeast. The British colonists were most likely drinking English ales.

Moonshine, an essential part of American alcohol history, dates back to Scotch-Irish immigrants who emigrated to Pennsylvania and the application mountains. They brought with them the still designs and knowledge of moonshine. This was during the 1700s. Moonshining quickly caught on throughout the rest of the region. The roads were very dangerous in the Appalachian Mountains. Farmers could more easily transport whiskey than corn and it was a more valuable process. Moonshine is a high-proof distilled spirit that is typically produced
illegally. In 1920 there was a temperance movement spreading across the US by religious groups who thought that alcohol consumption threatened the nation. This movement came to fruition with the passing of the 18th amendment which prohibited the production, consumption, and sale of alcohol. The great American sport of NASCAR actually has its origins from bootleggers racing stock cars in the Appalachian Mountains and on country roads during prohibition. Many farmers had no means to survive besides rigging up their cars to go fast enough to outrun the law and sell whiskey illegally. Naturally, these super-fast cars started racing each other. Eventually a track was built, and the rest is history. In 1933, the 21st amendment was passed, repealing prohibition.

The sale and consumption of alcohol again found its way into mainstream American culture and is a strong hold to this day. Within the past 3 decades, there has been an explosion of microbreweries across the nation. This was in large part due to more favorable legislation passed in the recent years that made consolidation of breweries more difficult. These laws deregulated home brewing and left over prohibition era laws.

According to a 2010 Global Status Report on Alcohol by WHO the United States is 48th in liters of alcohol consumed per capita in persons over the age of 15 with 9.2 liters consumed per year per person per capita. This also concluded that beer is the mostly widely consumed alcohol in the United States, by a landslide, followed by spirits then wine.

Wine:

Wine is made from fermented grapes. Yeast is used to convert the natural sugars of the grapes into alcohol anaerobically (without oxygen). White wine is produced by fermenting the juice of skinless grapes. This is made by pressing crushed grapes to extract a juice. Red wine, on
the other hand, comes from red or black grapes and is fermented in pulp that includes grape skins.

The wine making process begins with the picking of the grapes. This can be done either by hand with shears or by machines. The picking is done during the harvest time and is only done once per year. Next, the grapes are crushed. This can be done a variety of different ways. A destemmer is often used to remove the stems from the clusters as well as to lightly crush the grapes. For white wines, the grapes are then transferred to a press where they are crushed further. The extract juice is transferred to sediment tanks and the skins are left behind. After all of the sediment settles to the bottom of the tank, the juice is then racked, meaning it is filtered into another settling tank in order to ensure that all sediment is removed before fermentation begins. For red wines, after the destemmer, the grapes along with the skins go straight into a vat to start fermentation.

The next step in the process for both types of wine is fermentation. The grapes or juice is placed in large vats and yeast is then added so that the fermentation can take place. For red wines, carbon dioxide is released during fermentation which causes the grape skins to rise to the surface. The grapes are then pressed after fermentation is complete. Red wines then may spend several months aging in barrels. Whites are fermented grape juice so there are no skins to be removed in additional steps before barreling. Typically the same type of yeast can be used for both red and white wines. The final steps in the wine making process are aging and bottling. Wine can be aged anywhere from months to years. It is then placed in bottles using automated machinery.

Often time in red wines a slightly acidic or dry aftertaste can be observed. This is commonly referred to as a tannin. These tannins occur naturally in the skin of the grapes which is
why they are only present in red wines. Tannins are organic compounds that can be classified as polyphenols. They give the wine a characteristic dryness. Tannins are released from the skins of the grapes after they have been pressed. This occurs more in cabernet sauvignon than in lighter pinot noirs as they are produced from thicker skinned grapes. Finally, tannins act as a natural antioxidant to help preserve the wine.

**Common Types of Wine:**

Wines are often classified based on their location or vineyard. For example, wines can be classified as Italian, Spanish, American, or even as specific as Californian. They can also be classified by region that will typically contain multiple wineries, for example Sonoma County. Finally, wines can be classified strictly by winery alone. In a similar manner, wines can also be broadly classified by the type of grape and its location.

Champagne is a type of wine that is produced using a second fermentation which allows the CO₂ to stay in the wine. This step occurs in a sealed bottle which creates the carbonation. This bottle is placed in a cool cellar and allowed to slowly ferment, creating alcohol and carbon dioxide. The yeast cells die off after several months and the fermentation is complete. The champagne is then aged for years, giving it a toasty, yeasty characteristic taste. The reaction that occurs inside the bottle is:

\[
\text{Yeast} + \text{Sugar} = \text{Ethanol} + \text{CO}_2
\]

Chardonnay is produced from a green grape and is classified as a white wine. It originated in the Burgundy wine region of France, but these grapes are now grown everywhere around the globe. It typically has flavors of plum, apple, and pear.
Riesling is a white grape wine that originated in the Rhine region of Germany. The Riesling grape is aromatic, flowery, and highly acidic. In cool climates, Riesling wines have an apple and tree fruit taste. Whereas, warmer climate grapes tend to have peachy or citrusy notes.

Pinot Grigio is another type of white wine made from grayish-blue grapes. The word “pinot” means pine cone, referring to the pine like cluster of the grapes as they are picked. It is a full bodied wine with notes of melon and mango.

Pinot Noir is a red wine. It also originated in the Burgundy region of France and the grapes also cluster in the form of a pine cone. Pinot Noir tastes typically of strawberries, raspberries and cherries.

Merlot is a black (red) wine grape originally from the Bordeaux region of France. Its French translation is “little black bird”. Merlot will either taste of blackberry or raspberries and strawberries depending on the harvest time.

Cabernet Sauvignon is another red wine grape. It is grown in many climates globally ranging from Canada to Lebanon but originated in southwestern France. This is commonly thought of as the most popular red wine globally. Depending on climate, notes range from mint and cedar to black cherry and black olive.

Moscato originates from the Muscat family of grapes. It can be a variety of different colors and is thought to have originated from the Egyptians. It is typically grown in Italy, Australia, and Spain and has a very grapey aroma with notes of citrus and peach.
Beer:

All beer is produced via the fermentation of malt. Most basic beer production process follow the same steps. One will find these steps in nearly every brewery in the world. The basic 6 steps are: malting, kilning, milling, mashing, fermenting and bottling. The process begins with the harvesting of malts (various grains used in the production of beer). This step is pretty self-explanatory. The harvesting can either be done by hand or by machine. The next step in the process is malting. The main goal of malting is to isolate the enzymes and carbohydrates needed for brewing. This is done by heating, drying, and cracking the harvested malts. Malting begins with the germinating of grains. This is done by immersing them in water to encourage the grain to sprout, thus bringing the carbs out. Then the grains are dried to halt the process once the sprouting begins. The next step in the beer making process is kilning. This is considered the final stage of traditional malting. The goal if kilning is to significantly decrease the moisture content of the malt, drying it out. Once the malts have been dried to satisfaction, the milling process begins. This is where the outer layer, or husk, of the grain is removed by crushing. The inner layer, the endosperm, is broken up to allow for maximum carbohydrate harvest. This is accomplished through mashing liquid that is not warm enough to boil. In the mashing step, the crushed malt is placed in a hot vat of water. The goal of this step is to extract the enzymes and sugars from the malts that will be used in the brewing. This step produces liquid mixture of water and malt sugars called the wort. This is basically the unfermented beer. One the wort has been prepared, the fermentation step can begin. The wort must first be boiled. Once boiled, hops are added for flavor. The wort is then placed in vessels and yeast is finally added. This fermentation step is done at a variety of different temperatures and with different types of yeast depending on the beer type being produced. In this step, the yeast eats up the sugars in the wort and produces
both CO₂ and alcohol as products of this reaction. Yeast is a microorganism fungus that reproduces by budding. The fermentation step can last anywhere from a few weeks to many months, depending on the type of beer being produced. This process is essentially anaerobic, meaning without air, as the air would spoil the batch. The final step in the beer production process is bottling. This is done after the beer has been fully fermented. This operation is done differently based on the brewery, but it is typically and automated process where the finished liquid is pumped via pipes to the bottling or canning machines.

All beer is carbonated, but the extent of carbonation depends on a few factors. During the fermentation process, CO₂ is produced naturally from the fermentation reaction. Since the beer and carbonation are in a sealed process under pressure, the beer absorbs some of this CO₂, giving it its fizz. Natural carbonation can also be used during the bottling process. Here completely fermented beer is left unfiltered so that active yeast are still present. A small amount of sugar is added as the beer is bottled. The bottle is then sealed and the yeast eats the sugar to produce CO₂ which can then be absorbed by the beer.

The specific ingredients and processing details distinguisher between types of beer. Beer varieties are created mainly from the fermentation stage when the yeast is added. The length and temperature of the fermentation both have a large effect of the type of beer. Most beers fall into two categories: lagers and ales. These are characterized by their type of yeast used. Ales are produced using a top fermenting yeast, meaning that it sits on the top of the liquid in the vessel. Ales are typically fermented at room temperature (60-75°F) for a few weeks. Lagers are produced using bottom fermenting yeast, meaning that the yeast sits on the bottom of the barrel. Lagers have a longer fermentation time and are fermented at colder temperatures ranging from 25-50°F.
Types of Beer:

**Pale Ale** is an ale brewed with “pale” malts meaning the malts were lightly roasted, giving less of a burnt or cooked and more of a full flavor to the beer.

**Wheat beer** is an ale brewed with a larger wheat to barley ratio of malts than most ales. Because of this, its fermentation process includes the production of esters and other by-products. Wheat beer has a sweet and slightly tangy taste. The German Hefweisen is unfiltered wheat beer.

**India Pale Ale (IPA)** is a hoppy brew born out of the English pale ale tradition. When the British pale ale was being transported to the British colonies in India this beer would be over loaded with hops in order to preserve the brew for the long 6 month journey by sea.

**Amber Ale** is ale brewed with amber or crystal malts. A small amount of crystal or other colored malt is added to the basic pale ale mix to give amber ale its color. They are typically darker in color and have a slight caramel flavor.

**Porters** are dark ales consisting of hops and brown malts. This gives the porter a darker color than most other ales. Porters differ from stouts in that they do not contain a roasted barley flavor.

**Stout** is a beer characterized by its roasted flavor. This comes from the roasted barley. The term stout originated in the 1600 to 1700s. It is considered a stronger porter and has the characteristic dark look to it.

**Cider** is more similar to Champaign than beer but is often considered in beer conversations. It is made using pressed apples that are fermented with a longer strand of yeast that is not of the same family as beer yeast.
Spirits:

Spirits are made very similarly to wine and beer, via a fermentation process with yeast. However, what varies is the type of plant, fruit, or wine that is fermented. Additionally, spirits go through a distillation process in order to distill the purer alcohol product from the water. Each spirit starts with a different base fruit, plant, or sugar that then is fermented using yeast in a similar process to both beer and wine. The base ingredient is mashed, milled, or a combination of the two. The sugars and carbs are released into a wort used in fermentation. The different types of base material are typically what differentiates spirits, so this is discussed further below. After the standard fermentation process, the alcohol-water mixture is then separated using a distillation apparatus. Distilling operates on the principle of different boiling points. The ethanol will have a lower boiling point than that of water and other waste materials. Therefore, the distillation apparatus will heat the liquid to the boiling point of the mixture. High alcohol content vapor will boil off, separate from the low alcohol liquid. The first liquid to leave the still is referred to as the foreshot. This contains low-boiling light components such as methanol and ethanol. This high alcohol vapor will then be condensed, typically using cooling water. This condensation will be collected as finished product or to be distilled again for higher quality. Distillation methods will be discussed in detail in lesson 12. The thumper is a liquid filled tank that bubbles vapor through. This results in a higher proof alcohol.

Types of Spirits:

Brandy is an alcoholic beverage that is made from distilling wine (or any other sugar containing liquid). The fruit juice must be allowed to ferment and then the solution is boiled off so that the alcohol evaporates along with the fruity aromas. The water and bitterness is left behind as waste. Brandy tastes sweet like dried fruit and citrus zest.
**Whiskey** is an alcoholic beverage that is distilled from fermented grain mash. After the distillation process it is then aged in oak barrels to add flavor. There is a variety of different types of whiskey that will be discussed further.

**Bourbon** is a type of whiskey that must be made within the United States. It contains 51% corn and must be distilled at 160 proof or less, put into barrels at 125 proof or less, and aged in new oak charred barrels.

**Rye whiskey** is a type of whiskey that contains 51% rye grass and must also be aged in new, charred, American oak barrels.

**Tennessee whiskey** is produced exactly the same way as bourbon, but before the distilled spirit is barreled, it is charcoal filtered.

**Irish whiskey** is whiskey that is distilled in Ireland and must be aged a minimum of three years in oak barrels.

**Scotch** is whiskey that is distilled in Scotland and is made from primarily malted barley.

**Canadian whiskey** is whiskey that is distilled and aged in Canada. It is typically made of rye but other grains are often used.

**Rum** is a spirit made from crushed sugar cane stalks. The sugar cane juice is fermented and then distilled. In certain rums, the sugar cane juice is cooked into a syrup or molasses.

**Tequila** is a cooked and distilled spirit that is produced from the fermentation and distillation of the agave plant. Inulin, the sugars of this plant, contain long chain molecules. The sugars are allowed to ferment after being cooked and the solution is then distilled twice. Specialty yeast is
used in most operations, while some simply use naturally occurring yeast. In the United States, tequila must be at least 80 proof to sell.

**Gin** is a neutral grain spirit that is re-distilled with botanicals. It is produced from the fermentation of the juniper plant. In the United States, gin must be at least 80 proof.

**Vodka** is a spirit of Russian origin. It can be produced from any type of grain including wheat, rye, barley, or potatoes. The starches and sugars of the grains are allowed to ferment. It is then distilled multiple times through activated charcoal. It consists in its simplest form of water and alcohol with minimal impurities.

**Lesson 2 Unit Operations and Conversions:**

When measuring a value, the units used carry almost as much significance as the actual numerical value itself. For example, stating that the mass of something is 2 says next to nothing about the actual mass of the object. Units are what gives the numerical value physical significance and how to relate specific objects to others in the universe. It is necessary to measure things because measurements are key in explaining the physical world around us and in solving mathematical problems.

The most common variables that one measures are length, mass, temperature, and time. Almost everything else that one would measure can be broken down to these 4 things. Below is a table of common units used to express length, mass, time and temperature. Mass is defined as the amount of matter in an object and is typically measured on a scale. Length is defined as a measured distance or dimension. Time is defined as the period between 2 events and is relative. Temperature is the degree of intensity of the heat in an object.
<table>
<thead>
<tr>
<th>Base quantity</th>
<th>Standard units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>Foot (ft), meter (m)</td>
</tr>
<tr>
<td>Mass</td>
<td>Pound (lb), kilogram (kg)</td>
</tr>
<tr>
<td>Time</td>
<td>Second (s), Minute (min)</td>
</tr>
<tr>
<td>Temperature</td>
<td>Celsius (°C), Fahrenheit (°F)</td>
</tr>
</tbody>
</table>

Note the different common units for each quantity. These units were given in both the SI and English system of measurement respectively. The SI system of measurement or Système international is the most widely used system of measurement on a global scale. The base units for this system are meters, kilograms, and Celsius. Additionally, there are many other quantities than can be expressed in SI units, most of which will be discussed in detail later. Some additional measurements are volume, area, force, and pressure.

The SI system consists of a system of units of measurement built on base units. These base units are used when the values being measured are much too large or too small to be described using the base value. For example, the size of a small bug wouldn’t be described as 0.003m, instead one would say 3mm. These base units include:

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Value compared to base unit</th>
<th>Prefix Symbol</th>
<th>Amount needed to make base unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mil-</td>
<td>$10^{-3}$</td>
<td>M</td>
<td>1000</td>
</tr>
<tr>
<td>Centi-</td>
<td>$10^{-2}$</td>
<td>C</td>
<td>100</td>
</tr>
<tr>
<td>Deci-</td>
<td>$10^{-1}$</td>
<td>D</td>
<td>10</td>
</tr>
<tr>
<td>Base</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Deca-</td>
<td>$10^{1}$</td>
<td>da</td>
<td>0.1</td>
</tr>
<tr>
<td>Hecto-</td>
<td>$10^{2}$</td>
<td>H</td>
<td>0.01</td>
</tr>
<tr>
<td>Kilo-</td>
<td>$10^{3}$</td>
<td>K</td>
<td>0.001</td>
</tr>
<tr>
<td>Mega-</td>
<td>$10^{6}$</td>
<td>M</td>
<td>0.000001</td>
</tr>
</tbody>
</table>
The other system of measurement that was included in the prior table was the US Customary Units, or English system of measurement. These include pounds, feet, and Fahrenheit. The English system is used only within the United States and evolved from the previously used imperial or British units.

One of the most basic calculations in Chemical Engineering is unit conversion. It is one of the building blocks for many engineering problems. Now one may ask how to convert from kilograms to grams or centimeters to meters. This can all be done in a simple and systematic way, as each prefix is ten times greater than the previous. Conversion is a multistep process of division and multiplication by a numerical factor, often called a conversion factor. For example, to convert 10 meters to centimeters, it is known that there are 100 cm in 1 m. Therefore, the basic procedure to follow is:

\[
10 \text{ m} \times \frac{100 \text{ cm}}{1 \text{ m}} = 1,000 \text{ cm}
\]

To convert between units in the SI system, simply create a ratio (using a conversion factor) between the new or desired unit and the current unit. The current units will cancel out, leaving only the value of the new unit.

For the English system of units, conversions between units is a bit more difficult. There are not just a handful of bases or prefixes, but instead a few unique values for different amounts of length and volume. A table of conversions for the English system can be found below. The basic idea of conversions is the same as with SI units: create a ratio of the new unit to the old and multiple this by the old value to generate a new value in desired units.
Units for time are the same in both systems of measurements. The common conversions between time values are:

<table>
<thead>
<tr>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>60 s = 1 min</td>
</tr>
<tr>
<td>60 min = 1 hr</td>
</tr>
<tr>
<td>24 hr = 1 day</td>
</tr>
<tr>
<td>7 days = 1 wk</td>
</tr>
<tr>
<td>365 days = 1 year</td>
</tr>
<tr>
<td>52 wks = 1 year</td>
</tr>
</tbody>
</table>

It is also possible to convert from SI units to English units and vice versa. This is done in a similar manner by establishing conversion factors or ratios of English to SI units. Below is a table of common unit conversions between systems of measurement.

<table>
<thead>
<tr>
<th>SI Unit</th>
<th>English Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.54 cm</td>
<td>1 in</td>
</tr>
<tr>
<td>454 g</td>
<td>1 lb</td>
</tr>
<tr>
<td>1 m</td>
<td>3.2808 ft</td>
</tr>
<tr>
<td>3.785 l</td>
<td>1 gal</td>
</tr>
<tr>
<td>101325 Pa</td>
<td>14.7 psi (lb/ in²)</td>
</tr>
</tbody>
</table>

**Temperature:**

Temperature is defined as the degree or intensity of heat present in a substance or object. It is the absolute value of molecular motion. The scales for temperature are on a comparative basis. Converting between different temperature units is not as simple as previous conversions. There is not simple ratio to use to convert between the SI and English system of units. Recall that the SI unit of Temperature is Celsius and the English unit is Fahrenheit. In order to convert from
Celsius to Fahrenheit, an equation must be solved. These equations were derived from the basic notion that

\[ 212 \, ^\circ F \leftrightarrow 100 \, ^\circ C \]

\[ 32 \, ^\circ F \leftrightarrow 0 \, ^\circ C \]

At zero, \( 212-32 = 180 \leftrightarrow 100 - 0 \)

\[ \frac{180}{100} = \frac{9}{5} \]

To convert from Celsius to Fahrenheit:

\[ F = C \times \frac{9}{5} + 32 \]

To convert from Fahrenheit to Celsius:

\[ C = (F - 32) \times \frac{5}{9} \]

Absolute temperature is defined as the thermodynamic zero. It is the temperature of 0 degrees kelvin. Nothing in the universe can get this cold. To convert from Celsius to the SI standard unit of Kelvin of absolute temperature, simply add 273.15 to the temperature in Celsius. To convert from Fahrenheit to Rankine for absolute temperature, simply add 459.7 to the temperature in Fahrenheit.

For the Fahrenheit and Rankine scales, the interval between numbers is equivalent. The same is true for the Celsius and Kelvin scales. For example, a 5 degree Celsius difference is also a 5 degree Kelvin difference. The same does not apply between the Celsius and Fahrenheit scales.
A thermocouple is a device that measures temperature. They function on the creation of a potential difference or voltage drop between 2 different metals. These metals need to have dissimilar properties in order to create the necessary voltage drop. The metal pieces are joined at one end and separated at the other. There is a connection between how a metal conducts heat and electric current. Therefore the heat can develop a voltage drop or current in the metals. This voltage drop can be measured and then converted into a temperature reading. Standards of specific temperature can be used and their voltage drop measured. Then, mathematic equations can be developed in order to relate all future voltage readings to temperature readings. Thermocouples will be used during lab to relate a variety of different temperatures.
<table>
<thead>
<tr>
<th>Metric Conversion Chart</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Length</strong></td>
</tr>
<tr>
<td>When you know</td>
</tr>
<tr>
<td>millimeters</td>
</tr>
<tr>
<td>centimeters</td>
</tr>
<tr>
<td>meters</td>
</tr>
<tr>
<td>kilometers</td>
</tr>
<tr>
<td>inches</td>
</tr>
<tr>
<td>inches</td>
</tr>
<tr>
<td>feet</td>
</tr>
<tr>
<td>yards</td>
</tr>
<tr>
<td>miles</td>
</tr>
</tbody>
</table>

| **Mass and Weight**    |
| When you know          | Multiply by | To find |
| grams                  | 0.035       | ounce   |
| kilograms              | 2.20        | pounds  |
| kilograms              | 2.68        | pounds (apoth.) |
| tons (1,000 kg)        | 1.10        | short tons |
| ounces                 | 28.35       | grams   |
| ounces (apoth.)        | 31.10       | grams   |
| pounds                 | 0.45        | kilograms |
| pounds (apoth.)        | 0.37        | kilograms |
| short tons (2,000 lb)  | 0.91        | metric tons |

| **Speed**              |
| When you know          | Multiply by | To find |
| miles per hour         | 1.61        | kilometers per hour |
| kilometers per hour    | 0.62        | miles per hour |

| **Temperature**        |
| Degrees Fahrenheit     | °F − 32 + 1.8 | Degrees Celsius |
| Degrees Celsius         | °C + 32      | Degrees Fahrenheit |

| **Volume**             |
| When you know          | Multiply by | To find |
| milliliters            | 0.20        | teaspoons |
| milliliters            | 0.07        | tablespoons |
| milliliters            | 0.03        | fluid ounces |
| liters                 | 4.23        | cups |
| liters                 | 2.11        | pints |
| liters                 | 1.06        | quarts |
| liters                 | 0.26        | gallons |
| cubic meters           | 35.31       | cubic feet |
| cubic meters           | 1.31        | cubic yards |
| teaspoons              | 4.93        | milliliters |
| tablespoons            | 14.79       | milliliters |
| fluid ounces           | 29.57       | milliliters |
| cups                   | 0.24        | liters |
| pints                  | 0.47        | liters |
| quarts                 | 0.95        | liters |
| gallons                | 3.70        | liters |
| cubic feet             | 0.03        | cubic meters |
| cubic yards            | 0.76        | cubic meters |

| **Prefixes**           |
| Prefix                | Symbol | Factor |
| exa-                  | E      | 10^24  |
| peta-                 | P      | 10^15  |
| tera-                 | T      | 10^12  |
| giga-                 | G      | 10^9   |
| mega-                 | M      | 10^6   |
| kilo-                 | k      | 10^3   |
| hecto-                | h      | 10^2   |
| deca-                 | da     | 10     |
| deci-                 | d      | 10^-1  |
| centi-                | c      | 10^-2  |
| milli-                | m      | 10^-3  |
| micro-                | µ      | 10^-6  |
| nano-                 | n      | 10^-9  |
| pico-                 | p      | 10^-12 |
| femto-                | f      | 10^-15 |
| atto-                 | a      | 10^-18 |

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Lesson 3: More Measurements

Some common measures that are not included in the base units, but are still very commonly used in chemical engineering are pressure, force, density, specific gravity, volume. These are all units of measurement that have been derived from the base units of length, mass, and time. Additionally, the amount of material can be expressed in moles. This is another base unit as it cannot be broken down further but is not derived from length, time or mass.

Force is defined as the push or pull on an object due to its interaction with other object. Whenever 2 objects are interacting, there is some sort of force. For example, the earth’s gravitational field is always exerting a force on human beings. Forces can either be contact, for example, a child pushing another over, or action-at a distance, for example gravity. The units of force are Newtons in the SI system, or kg m/s^2. The English unit for force is pound force, or lbf.

Pressure is defined as the continuous physical force exerted on or against an object by something in contact with it. This contact does not have to be direct, it can also be indirect. Force example, when sitting in a chair, one is exerting pressure on the chair as well as the chair is asserting pressure the human. This is a direct force as there is direct contact. An example of an indirect force would be gravity; one doesn’t have to be in physical contact with gravity to know it exists. Typically, pressure is described as a force per unit of area. This is where the units of pressure come from. The SI unit of pressure is a Pascal which is a Newton/meter squared (N/m^2). A newton (N) is another derived unit used to describe force. It is equal to 1 kg m/s^2. The English unit for pressure is pound per square inch (lb/in^2). There are many of other units of pressured used for a variety of different reasons and scenarios, however, these are the most common and the official units of each system of measurement respectively. Conversion between units of pressure is done in the same way as seen for most SI to English and vice versa.
conversions. It is done by multiplying the current value by a conversion factor in order to obtain a new value in desired units. Recall that the conversion factor is a ratio relating one unit to the other, usually at its base level. Below is a table of conversions between different units of pressure:

<table>
<thead>
<tr>
<th>Pressure Conversions</th>
</tr>
</thead>
<tbody>
<tr>
<td>101,325 Pa = 14.7 psi</td>
</tr>
<tr>
<td>101.325 kPa = 14.7 psi</td>
</tr>
<tr>
<td>1 atm = 14.7 psi</td>
</tr>
<tr>
<td>1 psi = 760 mm Hg</td>
</tr>
<tr>
<td>1 bar = 100 kPa</td>
</tr>
<tr>
<td>1 atm = 101325 Pa</td>
</tr>
</tbody>
</table>

Atmospheric pressure is defined at the pressure at sea level exerted by the weight of the atmosphere. This is 14.7 psi in English units and 101.3 KPa in SI units. As the height above sea level increases, the atmospheric pressure decreases. However, for all standard calculations \( P_{\text{atm}} \) is the pressure at sea level. A gauge is a device often used in chemical processes and in chemistry to measure pressure. This gauge gives a pressure reading that already incorporates the atmospheric pressure as part of its calibration. Absolute pressure is the zero referenced against a perfect vacuum. It is a combination of gauge and atmospheric pressure. Therefore, the gauge pressure reading of any device relates to the atmospheric pressure and absolute pressure as:

\[
P_{\text{abs}} = P_g + P_{\text{atm}}
\]

There is a commonly used and accepted standard for temperature and pressure for ideal situations and calculations. This is used for calibration in many manufactures devices and in laboratory procedures. Standard pressure is 1 atm or 14.7 psi. Standard temperature is 273.15 K or 0 °C. This combination is often referred to as STP, standard temperature and pressure.
Area is defined as the amount of space inside the boundary of a flat object (2-dimensional). Surface area is a specific type of area that is the size or space of a surface only of an object. Cross sectional area is the area of a specific piece of a three dimensional object. This means that the object has been sliced as a cross section into a flat surface of which the dimensions and thus area can be measured. The units of area are length squared. For the SI system, the base unit is meters (m) and for the English system the base unit is feet (ft). For a square or rectangle, area is calculated as length times width.

\[ A = l \times w \]

For a triangle, the area is calculated as half of the base times the height.

\[ A = \frac{1}{2} b \times h \]

For circles the area is pi (3.14) times the radius squared. The radius is a straight line from the center of a circle to the outer edge.

\[ A = \pi r^2 \]

Volume is the amount of space that an object or substance occupies in three dimensional space. It is typically measured using units of length cubed, however not exclusively. When using units of length, volume is measured using an objects’ length x width x height. This
gives volume the unit of length cubed. For cylinders, volume is measured as the surface area of the cylinder times the height.

\[ V = \frac{\pi d^3}{6} \]

\[ V = \frac{\pi d^2 h}{4} \]

The most common measurement of volume in the metric system is meters\(^3\) and for the English system is ft\(^3\). Additionally, in the metric system, volume can also be described in units of liters. A liter is defined as the volume of a cube that is 10cm tall by 10cm wide by 10cm long. The volume of the cube is 1000cm\(^3\) therefore, the volume of one liter is equal to 1000cm\(^3\). This means that 1 cm\(^3\) is equal to 1 ml. In addition to ft\(^3\), another commonly used unit in the English system is the gallon. One gallon is equal to 0.134 ft\(^3\).

<table>
<thead>
<tr>
<th>2 cups (c) = 1 pint (pt)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 pint = 1 quart (qt)</td>
</tr>
<tr>
<td>32 oz = 1 quart</td>
</tr>
<tr>
<td>4 quart = 1 gallon</td>
</tr>
<tr>
<td>1 m(^3) = 1000 Liter (L)</td>
</tr>
<tr>
<td>1 pint = 34.677 cm(^3)</td>
</tr>
<tr>
<td>1 gallon = 277.42 cm(^3)</td>
</tr>
<tr>
<td>1 pint = 473 m</td>
</tr>
<tr>
<td>1 gal = 3.78 L</td>
</tr>
<tr>
<td>1 c = 237 mL</td>
</tr>
<tr>
<td>1 fl oz = 30 mL</td>
</tr>
</tbody>
</table>

The chart above can be used to convert between units. The process of conversion is the same as discussed previously; establish a conversion factor and solve.
A derived measurement of volume is volumetric flow rate. This is defined as volume per unit time and is typically associated with material moving through pipes or reactors. For example, a vessel or tank has units of volume. The volume of fluid moving through a pipe over a certain amount of time has units of volume per time, typically m^3/s or ft^3/s.

Density is the mass of a substance per unit volume. It is a measure of the compactness of an object or substance. The units of density in metric units are kg/m^3 and in English units are lb/ft^3. These units can also be converted into many other forms just as each of the base units can be converted.

Densitometers can be used to determine the density of a substance. This can be beneficial in helping to determine the concentration and identity of a material. It works by measuring the degree of darkness of a material. Basically, it is a light source that is aimed at a photoelectric cell. A sample is placed in between the light and the cell. Densitometers can either measure the light reflected from the surface or the transparency of the material. This can be directly correlated to the density of the material via calibration and mathematical equations.

Specific gravity is related to density. It is defined as the ratio of the density of the substance in question to the density of a specific standard. The common standard reference is water which has a density of 1 g/cm^3 or 0.0642 lb/ft^3.

The amount of a material can be measured in moles. All objects have matter and take up space. One mole of material is equal to 6.02 x 10^{23} molecules, particles or atoms. The purpose of the mole in chemistry is to describe the amount of atoms or molecules reacting together and what product they produce. This concept will be further discussed during the general chemistry.
Weight is the force of gravity acting upon an object. This measurement is often confused with mass, but there is a clear distinction. All objects have mass regardless of where they are located. Objects in space have mass. Mass is simply a measurement of matter in an object. On the other hand, weight is the force on an object due to the gravitational field it is in. Objects in space, therefore, do not have weight. The gravitation acceleration in SI units is 9.8 m/s$^2$ and in English units is 32.2 ft/s$^2$.

Measurements can be classified in one of two categories: extensive and intensive properties. Extensive properties depend on size of the material or object. These include volume, mass, surface area, and amount of substance. Intensive properties or bulk properties are independent of size and are physical properties of the material or object under specific conditions. These include density, specific gravity, pressure, boiling point, melting point, concentration, and temperature. Extensive properties can be made intensive by ratioing them. For example, density comes from the ratio of mass to volume. This will always be constant for a given chemical, no matter how much of the chemical is present.

**Lesson 4: Significant Figures**

Significant figures are the number of important digits that a numerical value has. They are used to express the degree of accuracy of the number. For example, the number 5.327 tells us that the digits 5, 3, and 2 are known with some degree of confidence and the last digit 7 is an estimate or approximation. The number of significant digits increases as the accuracy increases. This can be accomplished using more sensitive measurement equipment. There are many rules for counting and operations with significant figures. These are summarized below.

1. All digits 1-9 are significant, not matter where they fall within the number.
2. Zeros that are within a number are counted as significant. For example, in 9.302 there are 4 significant figures as the zero is significant.

3. Zeros that establish the location of the decimal point are not significant. For example, 32,000 has only 2 significant digits, not 5.

4. Trailing zeros that are after the decimal point, not setting the place are significant. For example, 5.00 has 3 significant figures.

When in doubt, assume that the zero is not significant. For example when a number is given such as 700 mL, assume that there is only 1 significant figure.

Mathematical Operations with Significant Figures:

The rule of thumb with significant figures in mathematical operations is that the final answer can have no more significant figures than the number of least significant figures in the original measurements.

In addition and subtraction, the answer can contain no more decimals than the least accurate measurement. For example,

\[ 167.0 + 0.9842 = 168.0 \]

The first number has one decimal place, therefore the final solution can only have one decimal place. Additionally, the first number has 4 significant digits and the second has 5, therefore the final solution can have no more than 4 significant digits.

In multiplication and division, the same principle applies. The solution can have no more significant figures than the least accurate measurement. However, for multiplication and division, the number of significant digits are counted instead of the decimal places. For example,
\[ \frac{1}{0.9804} \times (1.39) = 1.417789 \]

Which can be rounded and reduced to 3 significant figures as 1.42 as there are 4 significant digits in the first number and 3 in the second, therefore, the final solution can have no more than 3 significant digits.

There will be many problems like the examples above where one measurement is more accurate than another. In this situation, if the final solution has too many significant digits, then the answer must be rounded off. The rules for rounding are as follows:

1. If the answer ends in a 0, 1, 2, 3, or 4 (less than 5), then the solution can be rounded down to the preceding digit by dropping the final estimated or last digit. This is called underestimating.
2. If the answer ends in 5, 6, 7, 8, or 9 (greater than 5), then the solution can be rounded up by dropping the final digit and adding 1 to the next digit. This is called overestimating.

For example, if the answer is 1.2457 and only 4 significant digits are needed then the solution can be rounded off to 1.246. If the answer is 0.0984 and only 3 significant digits are needed then the solution can be rounded to 0.098.

When numbers are too large or too small to report reasonably with significant figures, one can use scientific notation. It is a great way to handle large or small numbers as it maintains the number of significant figures. It works by assigning a number with a specific amount of significant figures to a power of 10. This can be thought of as a multiplication problem: the first numerical value multiplied by 10 raised to the assigned power. The key thing to note, however is that in scientific notation, the numerical value can only have one digit before the decimal point. All other significant figures must fall after. For example, 0.000057 can be
written as $5.7 \times 10^5$ but not as $57 \times 10^{-6}$ as there are 2 digits before the decimal in the second number. Note: there is still only 2 significant figures in the scientific notion. A positive power of ten indicates that the decimal point will be moved to the right that amount of places. Conversely, a negative power of 10 signifies a move of the decimal point that number of places to the left.

**Lesson 5: Chemistry Basics**

In order to understand chemical engineering and chemical engineering systems, a basic understanding of chemistry is needed. Chemistry is defined as the study of substances, their identification, properties, interactions, reactions and changes.

To begin, the scientific method will be examined as a whole and how this plays into chemistry. The scientific method is a process for experimentation that is used to explore observations and answer questions about the natural world. The goal of the process is to come to a logical answer via question asking, experimentation, and analysis. It is a continuous process that is constantly evolving and changing to fit the specific needs of the scientist. The basic steps of the scientific method are 1) proposing a question, 2) systematic observation, 3) measurement, experimentation for formulation, 4) testing, and 5) modifying hypotheses.

The first step in the process, proposing a question is as simple as it sounds. What is to be learned? Some examples of question are: Do girls have faster reflexes than boys? Does hydrogen react with chlorine? Does the amount of catalyst effect the rate of reaction? This is typically posed after observation of the world and is often posed in order to better understand or explain a certain phenomenon.

The second step, systematic observation and research, is when as much information as possible is found on the subject. This is done through specific methods. Research
can be done by observing the phenomenon as well as by searching in textbooks, encyclopedias, or online. This is often referred to as background research.

The third step, constructing a hypothesis, is when all of the research and observations are put together in an attempt to make a prediction or answer the initial question. A hypothesis is an educated guess about how things work. It must be testable via experimentation and measurable data. For a hypothesis to be tested, it must be able to be proven incorrect. Therefore a hypothesis should contain clear and precise language. It should be free of vague phrases such as “may” or “could”.

The fourth step in the scientific method is testing. This is when the hypothesis is put to the test using a variety of laboratory level experiments. These tests must be well thought out and contain precise and efficient procedures. The test must be clear enough to be repeated in the future by another scientist. Furthermore, the test must be fair and unbiased. This means that the procedure cannot be skewed in order to obtain more favorable results to support the hypothesis. Typical tests include independent and dependent variables. One independent variable is changed at a time and the effects on the dependent variable are observed.

After testing has been conducted, the fifth step in the process is data analysis. This is when all of the data collected during the previous testing step is analyzed using calculations and graphs. Through analysis, it will be determined if the measurements and results support the hypothesis or not. It is not uncommon to determine that the results do not support the initial hypothesis. In this case, the results are still communicated but the process restarts itself by proposing a new hypothesis.
The final step in the scientific method is communicating the results. This can be done in a variety of ways but is most commonly done in a report. For this purpose of this class, results will be communicated in a lab report. Professional scientists will typically publish their results in journals or at conferences. This is the step where all of the findings and conclusions are shared. Here the conclusions from the experimental data are explained and how they do or do not support the hypothesis.

**Explaining the Physical World**

The most basic building blocks of everything in the world are atoms. Every object in the universe (including you) is made up of tiny particles called atoms. They are the building blocks of matter.

Elements are substances that cannot be broken down into simpler forms of matter. They are the basic forms of all matter in the universe. Elements are the basis for all chemical reactions and interactions. The most basic form of an element is one atom. Atoms consist of protons, neutrons, and electrons. Within the atom, there is a central part called the nucleus. It is in the nucleus that the protons and neutrons are housed. On the other hand, the electrons orbit about the nucleus in specific regions called shells. This will be discussed further in later chapters. Protons have a positive charge and electrons have a negative charge. Neutrons are neutral, meaning that they have no charge. The number of protons, electrons, and neutrons that an atom contains determines the type of atom or element. This number also determines if the atom is normal or an isotope. Isotopes are atoms of single elements that differ in the number of neutrons.

Molecules are made up of individual atoms. The technical definition of a molecule is the smallest unit of a chemical that retains the physical and chemical properties of a chemical.
A molecule is composed of one or more atoms. They can be composed of all the same atoms or different ones. A molecule of different elements combined together is referred to as a compound. These atoms are bonded together and represent the smallest fundamental unit of a chemical that can take part in a reaction. There are exactly $6.022 \times 10^{23}$ molecules in a mol of a substance.

Atoms are bonded together by the sharing or giving and receiving of electrons. When two atoms share a pair of electrons equally, it is called an ionic bond. When one element, typically the one with less electrons in its outer shell (valence electrons), gives up some of its electrons to another atom this is called a covalent bond.

As discussed previously, a mole is a unit used to describe the amount of a substance that is present. There are $6.022 \times 10^{23}$ molecules or atoms in a mole of substance. This is true for any substance or compound regardless of its composition. Moles are the unit typically used in chemical reactions to track substances because moles, like mass, must be maintained.

All of the known elements in the universe are summarized into one compact chart called the periodic table. It is laid out in a series of columns and rows to help group elements with similar properties and reactivity together. They are arranged in increasing atomic number order. Atomic number is the number of protons in the nucleus of the atom. The elements also appear in order from lightest to heaviest. This mass is referred to as atomic mass. It is defined as the average mass of protons and neutrons in the nucleus. Vertical columns on the table are called families and relate elements of similar properties. Horizontal rows on the table are simply called rows. Elements are grouped based on similar properties, for example the transition metals are all located in the middle rows of the table.
The periodic table is useful as it contains many pieces of information about each element in a compact table. The box for each element contains its symbol (abbreviation), number of protons (atomic number) and its molar mass (atomic mass). This mass is typically the amount of grams per mole of each element. It can also be reported in pounds per mole. This molar mass is very important when converting from grams to moles or moles to grams as it is the conversion factor. This number is clearly displayed underneath the element’s symbol on the periodic table.

For example, say there are 5.0 grams of oxygen and the molar mass of oxygen is 16.00 g/mol. If one wanted to convert from grams to moles one would simply set up a conversion factor equation as is done for unit conversions:

\[
5 \text{ grams } O \times \frac{1 \text{ mol } O}{16 \text{ grams } O} = 0.32 \text{ mol } O
\]

This same equation can be done for any element on the periodic table to convert grams to moles and vice versa.

Now that the molar mass of each individual element can be located, the molar mass of a compound can be calculated. This is relatively easy to do if the number of atoms of each element in the compound is known. To determine the molar mass of a mixture, the molar masses of each individual atom or element are added together. If the molar mass of water (whose formula is H₂O) is unknown, one would simply need to know the molar mass of both oxygen and hydrogen in order to calculate it. The molar mass of hydrogen is 1.01 g/mol and recall oxygen is 16.00 g/mol. Therefore, the molar mass of water can be calculated as:

\[
1.01 \times 2 + 16.00 = 18.02
\]
Note that the molar mass of water was multiplied by 2. This is because there are 2 atoms of hydrogen in a molecule of water. This is an important lesson to note: the molar mass of each element is multiplied by the number of atoms of that element in the compound.

For a compound to be considered organic, it must contain carbon molecules covalently bonded to other elements. There are many different types of hydrocarbons that can be split into long, medium and short chains. These hydrocarbons are named based on the number of carbons surrounding it. For example, methane is a single carbon bonded to hydrogens. Ethane is also a simple molecule made of 2 carbons bonded together with hydrogens surrounding them. Similarly, propane (3 carbons) and pentane (4 carbons) are found often throughout research and nature.

The general formula for sugar is \( \text{C}_6\text{H}_{12}\text{O}_6 \). Since this compound only consists of carbon, hydrogen, and occasionally oxygen, this is considered an organic substance. Sugar is one of the main ingredients needed for fermentation to occur.

**Solids, liquids and gases**

There are 4 distinct phases of matter found on earth: solid, liquid, gas, and plasma. For the purpose of this course, only the first 3 phases will be studied. Substances are constantly changing phases in chemical engineering reactions. As such, it is important to learn the different phases of matter and their properties. The first phase to discuss is solid. Solids are firm and ridged. They have a set volume, and cannot be significantly compressed. This means that they take up a finite amount of space and that their shape cannot be easily changed. Liquids are fluids that have a finite volume. They typically cannot be compressed by very much, but their shape can vary based on their container. Finally, gases are the most fluid of the three phases. They have
no finite volume or shape and instead can expand to fit the size of any container. Gases can also be compressed and are typically found at higher temperatures than the other phases. Particles have a great degree of motion in gases and are constantly bumping into each other. On the other hand, particles in solids are tightly packed together and relatively stationary. Liquid molecular motion is somewhere in the middle of these two extremes.

Each element and compound has its own unique temperature and pressure regions in which each phase can be found. Specific phase charts can be used to determine the conditions for each of these phases for each substance. In specific phase charts, there are sublimation, evaporation and melting curves. This indicates the outer regions or boundaries of each phase and at which conditions multiple phases can be present. These lines indicate a phase change. During a phase change, temperature and pressure remain constant. The only physical difference in the substance is its form. There is exactly one set of conditions for each substance where all 3 phases can exist in unison.

**Chemical equations and reactions**

Reactions cause a shift in the molecular structure of compounds. They are the basis for most chemical engineering problems as reactions are how most compounds in our universe are created. In order for a reaction to occur, chemical compounds must interact with each other. This means that the chemicals must share or exchange electrons. Recall that this phenomena is known as bonding. In a chemical reaction, bonds are created and destroyed, forming new substances as a result.

In every chemical reaction there are reactants and products. The reactants are the starting materials of a reaction. Conversely, products are what is created as a result of the
reaction. A chemical equation is a structured statement of reactants and products with their respective amounts. Equations must be written explicitly for every reaction. This is done by first writing out the chemical formulas of the reactants. Next, if the products are already known, simply draw an arrow from the reactants to the products. These are the 2 sides of the equation. In some cases, the reactants are not known and it becomes necessary to make educated guesses based on reactivity, solubility and other properties of the reactants. This course will not cover these kinds of complex equations. Note that when a chemical reaction equation is written, all the atoms found on the reactant side of the equation must also be present on the products side of the equation in one form or another. This is called balancing chemical reactions. It is necessary to count the number of each element on the reactants side and ensure that there is an equal number of each element on the products side. These elements will be bonded in different ways. Since moles and mass must always be conserved, the atom must be present in equal amounts on both sides of the equation.

Once the chemical reaction equation is written and the reactants and products are confirmed, it is then necessary to balance the equation. For instance, in the formation of water, 2 atoms of hydrogen react with one of oxygen to form water. Oxygen and hydrogen, however are rarely present in nature as a single atom. Instead 2 oxygen atoms and 2 hydrogen atoms are commonly found already bonded together respectively. In order to write a balanced chemical equation for the formation of water, it is necessary to begin with the basic reactants and products:

$$H_2 + O_2 \rightarrow H_2O$$

Note that the above equation is not balanced. There are 2 hydrogen molecules on the left hand side as well as the right hand side, but there are 2 oxygen molecules on the LHS and only 1 on the RHS. Therefore, one must add multiples of the original elements until both sides are
balanced. By doubling the amount of water produced, the oxygen reactant is balanced, but now there is double the amount of hydrogen on the products side as the reactant side. This can be fixed by doubling the amount of hydrogen reacting.

\[ 2H_2 + O_2 \rightarrow 2H_2O \]

Now the chemical reaction equation is balanced. There is an equal amount of hydrogen on both sides. Similarly, the amount of oxygen is balanced on both sides of the equation as well. Once a chemical equation is balanced, the stoichiometric ratio of each reactant and product can be obtained. The stoichiometric ratio is the ideal number of moles of each participant needed for the reaction to occur to completion. From the above equation, it is seen that the ratio of hydrogen to oxygen is 2:1. Similarly, the ratio of hydrogen to water is 1:1. Finally, the ratio of oxygen to water is 1:2.

Often times in a reaction, there is one reactant this is fed in excess and another that has a finite amount. This typically because one of the reactants is much cheaper than the other or for conversion purposes. The reactant that controls the amount of product produced and how much of the other reactant is converted is called the limiting reactant. For example, if there are 4 graham crackers and chocolate but only 3 marshmallows then the limiting reactant is the marshmallows as they determine how many s’mores can be made. To identify the limiting reactant, an analysis of all reactants is needed. The stoichiometric ratio of the equation must be used to determine which reactant produces the least amount of product by mass. This will also require the use of molar mass and moles to grams conversions. There will not be any specific problems with calculating limiting reactant in this class but it is important to note what a limiting reactant is and how it can affect a chemical reaction.
Activation energy

The amount of energy needed in order to begin a chemical reaction is called activation energy. This is commonly referred to as the energy needed to overcome the initial energy barrier. It is the joules or btu that are needed in order for a reaction to take place. If there is not enough activation energy present, then the reaction will not occur. Conversely, if there is more energy present than the minimum activation energy, then of course the reaction will occur! The reacting molecules need this energy in order to be brought together to collide in the correct orientation.

A catalyst is an additive that speeds up a chemical reaction. It has no effect on the amount of reactants and products of the reaction. The catalyst simply serves to decrease the speed up the reaction. To be considered a catalyst a material must: increase the rate of reaction, not be consumed by the reaction, be on a rather small ratio to the reactants, and finally, not change the equilibrium of the reaction. Catalysts typically reduce the activation energy needed for a reaction by changing the reaction mechanism so that less energy is needed for the reaction to proceed.

Equilibrium

Chemical reactions convert reactants into products. However, there are reactions where products can be converted back into reactants. When the rate of reactants consumed is equal to the rate of products returning to reactants, the system is said to be in chemical equilibrium. Put simply, this is when the rate of the forward reaction is equal to the rate of the reverse reaction. This occurs when the concentration of the products and reactants do not change over time. Do not be confused, this does not mean that the reaction has completely stopped! It
just means that what is being produced is also returning back to become reactants at a stable and equal rate. Chemical equilibrium deals with the level of reversibility of the reaction. If the reaction is highly reversible, then the equilibrium constant will be quite low. If the reaction is highly irreversible, then the equilibrium constant will be high. This equilibrium constant is calculated as the ratio of concentration of products to reactants.

When the reaction equation is,

\[ aA + bB \rightarrow cC + dD \]

\[ K = \frac{[C]^c[D]^d}{[A]^a[B]^b} = \frac{[\text{products}]}{[\text{reactants}]} \]

Where the brackets indicate concentration measurements and the exponents are the coefficients of each species in the balanced chemical reaction.

**Chemical Processes**

To begin, the two basic processes used in fermentation and other cell sized operations will be discussed. The first is an aerobic process. This type of system uses air as a reactant or catalyst in the reaction. The next is called anaerobic. This is when the reaction occurs without any oxygen necessary. Fermentation is an anaerobic process. This means that oxygen is limited during the reaction. This is the case for all beer brewing, wine making and spirit producing operations. Without oxygen, the yeast cells begin to eat up the sugar. This is how alcohol and water are created as by products. Since fermentation results from the lack of oxygen, it is the primary means of ATP energy in a production cell.

Finally, cellular respiration is when a cell extracts the energy from glucose using oxygen. This is done in many of the cells throughout the human body.
Lesson 6: Basics of Energy

In this lesson the basics of energy and power will be explored. Energy is present in all processes in our universe. According to the first law of thermodynamics, energy cannot be created or destroyed. The same is true of mass. This means that all the energy in the universe has been present since the beginning of time. Throughout history it has been converted and changed, but never created. This lesson energy conservation and conversion will be discussed. Many other concepts relating to energy such as power and specific types of energy will also be explored.

The logical place to begin is with the general mass balance equation. This is also applicable for the energy of the system which will be discussed later in the course. The general mass balance equation is:

\[ \text{Accumulation} = \text{In} - \text{Out} + \text{Created} - \text{Destroyed} \]

The overall solution to this equation must always be zero. All mass involved in a certain process must be accounted for as it cannot be generated or destroyed completely. Typically for the purpose of this class, the process will be steady state, meaning that the accumulation rate will be equal to zero so the focus will be on the right hand side of the equation. The general mass balance equation can also be equated to the differential conservation equation. It is the same general formula, however all values are in rate form, meaning mass/time or energy/time.

As stated previously, this conservation equation can also be applied to the concept of energy. Energy is the capacity to do work. In energy equations initial and final conditions of the systems in question are examined, not necessarily just screenshots in time. The general equation for total energy of a system is:

\[ E = U + KE + PE \]
Where $E$ is energy, $U$ is internal energy, $KE$ is kinetic energy and $PE$ is potential energy. Internal energy is the energy within a chemical due to its thermodynamic state and inner molecules. Kinetic energy is the energy of a chemical due to its motion. It is also known as mechanical energy. Potential energy has a variety of different forms including gravitational $PE$, chemical $PE$, elastic (spring) $PE$, and electrical $PE$. First, gravitational $PE$ is the energy of a chemical or object due to its location within space. For example, an object 10 feet up in the air has more potential energy than an object at ground level. The equation for this type of $PE$ is

$$PE_G = mgh$$

which is mass times gravitational acceleration times height of the object. Chemical potential energy is the energy of a chemical that can be absorbed or released during a chemical reaction. This is related to free energy of the chemical, which is beyond the scope of this class. Elastic or spring $PE$ is energy of a spring due to its position. When a spring is stretched or compressed it wants to get back to its original resting position. This potential energy within the spring to spring back to its resting position is defined as spring potential energy. The equation for this type of energy is

$$PE_S = \frac{1}{2} kx^2$$

Where $k$ is the spring constant and $x$ is the displacement distance. Finally, electrical potential is beyond the scope of this class but deals with the configuration or location of point charges in an electric field.

Potential energy can be converted to kinetic energy and vice versa. For example, the object 10 feet in the air could suddenly fall due to gravity. It has then lost its potential energy but it is now in motion and thus has kinetic energy. Similarly, a car going 60mph that comes to
an abrupt stop on a flat road has lost all of its kinetic energy, however, this energy has been transferred to heat (another form of energy) via kinetic friction. Again no energy can be created or destroyed so all potential and kinetic energy changes must balance out.

The unit for energy in the SI system of measurement is a joule. This is defined as 1 kg/m$^2$. In earth’s 9.8 m$^2$/s gravity, a 102 g object 1 m above sea level has 1 joule of potential energy. The unit for energy in the English system is a foot-pound (lb$\text{f}$). This is defined as the energy needed to lift one pound 1 foot in the earth’s gravitational field.

Work is defined in a variety of different ways for different applications in our lives. One is typically familiar with the definition of work as a job or task to accomplish. In chemistry and chemical engineering, however, this term has a different definition. When a force is applied to an object, causing the object to move, work is being done on the object by that force. Work can be either positive or negative depending on the displacement or movement of the object. There is also such a thing as expansion work. This is when a gas expands in a controlled environment, increasing the overall volume of the system. The definition of work of expansion is $W = -P \, dV$. Work fits into the overall energy equation; $E = W + q$. Then units of work are the same as those of energy, joules (J).

Power is the rate of doing work; the amount of energy consumed per unit of time. The units of power are joule/second or Watts (W) in the SI system and foot-pounds per minute in the English system.

To give a bit more background on energy and to relate it to real world quantities, the energy content of some commonly used energy sources will be discussed. Oil, gas, and other biofuels are typically referred to as energy. This is because they do work on a system either
producing heat or motion. One gallon of gasoline has roughly $1.3 \times 10^8$ Joules of energy.

Comparatively, 1.5 gallons of ethanol, the alcohol most commonly found in alcoholic beverages, has the same energy equivalent as one gallon of gas. Similarly, 1.54 gallons of liquefied natural gas (LNG) has the same equivalent as one gallon of gas. 2.0 gallons of methanol has roughly the same heating value as 1.0 gallons of gasoline. Finally, the energy content of 1 kg of hydrogen has the same heating value as that of 1.0 gallon of gasoline.

When the materials discussed above as well as more are burned for energy, a certain amount of carbon dioxide (CO$_2$) is emitted. In recent years, there has been many concerns with CO$_2$ emissions, global warming, and reducing said emissions. For the same amount of energy released, here is a list of which substances produce the most CO$_2$ emissions.

Coal > Diesel > Gas > Propane > Natural Gas (methane)

As seen above, coal produces the most emissions whereas methane produces the least. This among, other reasons, is why there has been such a shift towards natural gas consumption in the United States and globally in recent years.

Compressed natural gas (CNG) is simply methane stored at high pressures. It can be used as a fuel for internal combustion engines, which is how most cars operate. Compressed natural gas is also a much cleaner burn than many other fuel sources and is safer in the event of a chemical spill. It can be found abundantly in nature underground and near oil deposits. It can also be harvested from landfills and waste water treatment sites. This type of CNG is commonly referred to as biogas. Compressed natural gas is compressed methane that has been reduced to less than 1% of the volume occupied by methane at STP (standard temperature and pressure). Automakers have developed cars that run on CNG, either exclusively or as a dual fuel. Dedicated
engine means that the car runs exclusively on CNG, whereas, dual fuel systems can run compressed natural gas and gasoline. CNG cars are popular in Iran, Pakistan, and Delhi, India and are growing in popularity globally due to increasing gas prices. CNG cars are typically lower maintenance than traditional vehicles and have no loss or evaporation of fuel due to sealed systems. One major disadvantage to CNG vehicles are that the storage tanks require more space than traditional fuel tanks. CNG can also be used to produce syngas, a vapor that contains hydrogen and carbon monoxide. Besides CNG, syngas can also be produced from coal or biomass. It is then used to produce ammonia, methanol, and many other chemicals including many plastics, polymers and liquid fuels.

Another alternative fuel source that is worth noting is E85. This is a flex fuel mixture of gasoline and ethanol. This fuel contains somewhere between 51-85% ethanol (in the United States) whereas most gasolines contain less than 10%. This ratio varies as the heating value of ethanol is less than that of gasoline and thus makes it more difficult to run engines in colder weather. E85 cars are commonly used around the world in many established and developing countries, typically countries with warmer climates. It reduces exhaust emissions and reduces dependence on any one particular type of fuel. Vehicles that run on flex fuel do require some different parts than regular automobiles however. They need special engine timing as the engine requires more power to run. Similarly, some require specialized ethanol resistant parts and coatings. Both the gasoline and alcohol can be stored in the same fuel tank within the vehicle. Certain automakers are currently researching ways to make E85 and other low-gasoline input cars more readily available to the public. Two major cars available in flex fuel models are the Ford Tarus and the Dodge Caravan.
Latent heat is defined as the energy absorbed or released during the constant temperature process. This is commonly discussed in phase change problems. For example, the heat of vaporization is used in problems involving evaporation of a liquid to a gas. Heat of sublimation is used in processes where substances are changed from a solid to a gas. Similarly, heat of fusion is used in melting processes (solid to liquid). In each of these cases, a phase change occurs at constant temperature and pressure. These heats are recorded and tabulated for a variety of different temperatures and pressures and are used to solve energy balances during each of their respective processes. When a substance undergoes one of these processes, their internal energy changes (U in the previous energy balance equation).

The ideal gas law can be used when common gases are under mild or ideal conditions such as STP. Recall that STP is standard temperature and pressure and refers to 273K and 1 atm. Ideal gases have very low density so that the force between their molecules is weak. No intermolecular forces are at work and all internal energy is kinetic. This results in a simple correlation among properties. The law states that:

\[ PV = nRT \]

Where P is pressure, V is volume, n is the number of moles, R is the ideal gas constant, and T is the absolute temperature. This ideal gas constant is a specific and tabulated value for a variety of different pressure, volume and temperature units. Changes in energy in an ideal gas will result in a change in temperature.
Lesson 7: Basics of Chemical Engineering

Building blocks of systems:

Within chemical engineering, there are 3 different systems that one can encounter. The first is an isolated system. This is where no energy or mass is transferred across the system boundaries.

The second type of system is a closed system. This is when no mass is transferred but energy is transferred across the system boundaries. This means that the energy balance equation is \( \Delta E = Q - W \).

Finally, an open system is one where both mass and energy are transferred across system boundaries. For an open system, a full energy balance must be done including accumulation, in, and out terms.

Isolated systems can also be either rigid or non-rigid. A rigid system is one that does not store energy. Therefore, there is no change in internal energy. A non-rigid system is one that can store energy. Therefore, there can be changes in internal energy of the system.

There are certain types of equipment that are very common in chemical engineering processes. They have individual characteristics and specific purposes.

A vessel is a container, often referred to as a tank, which stores gases or liquids. No reactions take place in a vessel, but they are usually kept at a specific temperature and pressure.

A mixer is a simple piece of equipment used to combine two or more process streams together into one. These stream coming in should all be at the same conditions (P and T) so the mixing is ideal.
A compressor is an important piece of equipment for gases. It is a mechanical device that is used to increase the pressure of a gas by reducing its volume. Thus the gas is compressed. This is often used in recycle streams or to move gases from one vessel to another.

Pumps are similar to compressors but for liquid streams. They use an impeller to turn rotational kinetic energy into hydrodynamic (fluid) energy. This results in an increased pressure and fluid flow rate. Pumps are used to move liquids from process to process or vessel.

Turbines are the opposite of pumps. They are machines designed to capture energy from a fluid so it can be put to use in other operations. Therefore, they are an energy generating device as opposed to the energy consumption of a pump or compressor.

A reactor is a vessel where a chemical reaction takes place. There are a wide variety of reactors available for different purposes depending on the desired outcome. Some examples of reactors are batch, continuous, and semi-batch. Reactors are one of the key components in most chemical engineering processes. They are where the product is produced from the reactants.

A separator is a unit process that is used to separate the pure product from the waste products and reactants of the chemical reaction. This is another key component of chemical processes as the product is no good if it is mixed with other impurities. A common type of separator is a distillation column like one that is used in alcoholic spirit production. Recall that this type of separator relies on a difference in boiling points within the chemicals. Some other types of separators are absorbers, scrubbers, and membranes. Separators will be discussed further in a later lesson.

Once the final product has been separated from the unreacted reactants and the waste, the unused reactants can be fed back into the beginning of the process to be reacted. This
is called a recycle stream. They help to reduce the amount of feed stock needed by recycling back unreacted reactants. They are beneficial in cutting costs and also in helping to keep stoichiometric ratios to the reactor constant.

A still is an apparatus used to distill liquid mixtures by heating to selectively boil the more volatile component. The resulting vapor is then cooled to condense it back to the purified liquid state. Recall that still are used in distillation of alcohol for production at small scale distilleries and moonshine making.

Plate and Frame filtration is another separation procedure that is used for solid liquid systems. The apparatus consists of a solid metal frame with individual plates inside with filters on each plate. The solid liquid slurry is pumped through the apparatus using a centrifugal pump. As the slurry passes through the filters, the solid particles are left behind as the liquid passes through. The driving force for this filtration is pressure which is generated from the pump. Solid cakes build up on the filter paper while the purified liquid passes through the porous plates. This type of process is used in the production of beer to separate the yeast and other residual particles from the final liquid alcohol.

The engineering design method is similar to that of the scientific method discussed in lesson 5. However, there are a few minor changes and additions. The steps of the Engineering design method include: defining the problem, doing research, specifying requirements, developing solutions, choosing the best solution, building a prototype, testing and redesigning. These are the basic steps used to solve real world engineering problems as well as problems encountered on the classroom level.
There are also a wide variety of processes that could appear in a chemical engineering reaction problem. The first type is a batch process. This is a closed system where no mass or energy is transferred across boundaries. Chemicals are initially added to the system and allowed to react in a fixed volume. The second type of process is a continuous process. This is an open system, but is typically steady state for the purpose of this class, meaning that the accumulation term is zero. Mass both enters and exits the system during this process. An example of a continuous process is alcohol distillation. Another type of process is semi-batch. Semi-batch is a hybrid of both batch and continuous and is an open system. There is a mass transfer into the boundaries, but it does not exit the system.

**Solving Chemical Engineering Problems:**

Typical engineering problems are presented in word form and need to be interpreted. The goal is to create a general process diagram to understand what is occurring in the system. This is done primarily using the information above on different types of systems and processes. For example, if the problem states that it is a batch process, then no mass or energy enters or exits. For these problems, process block diagrams will be drawn in order to explain what is going on in the problem. For these types of diagrams, arrows and blocks will be used to depict how the process flows. For instance, for a distillation column, one will simply create a block that says separation equipment inside. The next step is to write down all of the given or known information and assign them variables. Similarly, write down what the problem is asking for. Finally, label all of the unknowns with variables to be solved for during analysis.

When presented with a chemical engineering problem it is important to know if enough information is supplied in order to solve. One way to determine this is through a degree of freedom analysis. In this analysis, the number of unknowns in the problem are counted as well
as the number of independent equations that can be used to solve. The equation used for analysis is:

\[ N_{df} = \# \text{ unknowns} - \# \text{ independent equations} \]

If the number of degrees of freedom is equal to zero then the problem can be solved. This is the ideal case. If the Ndf is greater than zero then the problem is underspecified and more independent equations or information is needed. This is the time to look for more relationships within the data. If the Ndf is less than zero, then the problem is over specified and the useful data will need to be sorted out.

For some engineering processes, it is necessary to add excess feed to the inlet stream. This can be done for a number of different reasons. Primarily it is done to increase equilibrium or selectivity of a certain product. A reactant is termed in excess when more is fed than its stoichiometric ratio. In some cases excess feed is introduced in order to generate a specific feed ratio into a reactor. This is typically done to increase conversion and selectivity.

There is a large difference between flow rate, mass flow rate and velocity. While they are interrelated, their units are different and they describe different aspects of a fluid. Velocity is the speed of a fluid in a given direction (note it is the same as speed in magnitude but not in practice because velocity is a vector that requires a direction). It is calculated as distance over time, which is its units as well. Mass flow rate is the mass of the fluid that moves through a certain area over time. Its units are mass/time. Molar flow rate is the moles of a fluid that moves through a given area over time. Its units are mol/time. Flow rate is the flow of volume over time through a certain area. It is calculated in a number of ways such as velocity x area, mass flow over density, and/or volume over time.
Fractions are used to describe the amount of material or matter of each substance in a chemical compound. Two expressions of concentration that are commonly used in chemical engineering are mole fractions and mass fractions. As the name implies, a mole fraction is the amount of moles of a given substance that make up the entire solution or compound. It is calculated as the moles of a specific substance divided by the total moles of solution or mixture. A mass fraction, similar to mole fraction, is the ratio of mass of one substance to the total mass of the solution or compound. Both of these fractions are ways of expressing the composition of a substance. Furthermore, the sum of all mass and mole fractions in a given solution or compound must be equal to 1. These fractions are not interchangeable but can be used along with other information to solve for each other. For example, to calculate the mole fraction from the mass fraction:

1. The total mass of the solution times the mass fraction is the mass of each individual substance. Calculate the mass of each component in the compound.
2. Then divide the mass of the substance by its molar mass in order to calculate the moles of the individual substance.
3. Finally, once all of the molar masses have been obtained, then the mole fractions of each substance can be calculated using the total number of moles of the compound.

The reverse process can be used to calculate mass fractions from mole fractions.

**Dew point and boiling point**

A common calculation that appears in many chemical engineering problems is that of boiling point and dew point temperatures. These are essential in problems involving multiple states of matter (for example evaporation and condensation). A vapor pressure is the
pressure at which a substance will evaporate from a liquid to a vapor at a given temperature. It is also referred to as the saturation pressure as this is the pressure of fully saturated vapor. The vapor pressure can be calculated using a number of techniques as well as tabulated data. For the purpose of this class, the antione equation will be used. The Antione equation is a basic formula that relies of specific calculated constant for each individual substance. These tables of constants can be widely found online and in all chemical engineering textbooks. The basic antione equation is:

$$\log P_{\text{sat}} = A - \frac{B}{(T+C)}$$

Depending on the table of reference, the pressure and temperature will need to be in the specified units. These are typically mm Hg and Kelvin respectively, but not always. As one can see, pressure varies with temperature, so as temperature increases, so does the vapor pressure of the substance. From this equation, the saturation pressure at a given temperature or the temperature of a given saturation pressure can be calculated. The calculated temperature is referred to as the boiling point of the substance or mixture.

For a single pure substance, there is only one unique saturation pressure for each given temperature. These are the conditions at which phase equilibrium can be achieved. This means that the liquid and vapor states are at equilibrium with each other. The amount of substance evaporating to vapor is equal to the amount of substance condensing into liquid.

For mixtures, this calculation becomes a bit more complex. Phase equilibrium conditions can still be calculated using the Antione equation, but the final solution will be a mixture of all the substances in the mixture’s individual properties. The saturation pressure as well as boiling and dew point temperatures will vary depending on the concentration. These
values will never be lower or higher than the value for the pure substances at the given conditions. For instance, if one substance has a lower boiling point then it will be begin to evaporate at a lower temperature than the other components. Therefore, the concentration of the vapor and liquid phases will be different for mixtures.

For these situations, the bubble point and dew point temperatures are calculated. The limits of phase change for each substance will be examined. This means examining the properties of each individual component before putting it all together. The bubble point is the point at which the first drop of a liquid mixture begins to vaporize. Conversely, the dew point is the point at which the first drop of a gaseous mixture begins to condense. When these points are plotted on the same graph, this is call a P \(_{xy}\) or T \(_{xy}\) diagram. The xy stands for liquid and vapor concentrations. An equation called Raoult’s law can be used to determine the composition of both the vapor and liquid phases as well as the saturation pressure when 2 out of the 3 above variables are known. It is defined as:

\[
 yP = xP^{sat}
\]

Where \(y\) is the vapor mole fraction, \(x\) is the liquid mole fraction, \(P\) is the system pressure and \(P^{sat}\) is the vapor pressure.

Similar to Raoult’s law, Henry’s law can also be used to solve vapor-liquid equilibrium problems. Henry’s law relates the mass fraction in the liquid phase to the partial pressure in the vapor phase for a given chemical. This correlation, however, can only be used at relatively low concentrations. Henry’s law states:

\[
 yP = xH
\]
Where y is the vapor mole fraction and x is the liquid mole fraction. P is the pressure of the system and H is the tabulated Henry’s law constant.

**Measures of Chemical Engineering Processes and Products**

During the course of chemical engineering processes, it is necessary to define certain variables as measurements of the efficiency of the system. They often describe how well the system is operating, to what extent the desired reactions occur, and what is the composition of the finished product. These measurements are also key information in solving an equilibrium system because they can be used to determine mole and mass fractions of the final products as well as the amount of reactants and products present.

Efficiency is defined as the actual or experimental outcome over the theoretical or calculated outcome for a given situation. For example, one can calculate the theoretical amount of energy produced but then experimentally get a lower value. This ratio would be the efficiency of the system.

\[
\text{efficiency} = \frac{\text{actual}}{\text{theoretical}}
\]

Conversion is defined as the ratio of the amount of reactant consumed to the amount of reactant fed in. When conversion is high, the reaction is product favoring. The ideal value for conversion is 1.0 when the creation of a specific product is desired.

\[
\frac{\text{amount of reactant consumed}}{\text{amount of reactant fed in}}
\]
Yield is defined as the ratio of the desired product formed to the total amount that could have been made. Conversion can be used to determine if side reactions occurred. The ideal value for yield is 1.0, however this is rarely achieved in practice.

\[
\frac{\text{desired product formed}}{\text{total theoretical amount that could have been formed}}
\]

Purity is defined in chemistry and chemical engineering as the degree to which a substance is unmixed or diluted with extra material. It is expressed as a percentage of the mass of a substance to the mass of the impure substance. The ideal, yet practically unattainable, value for purity is 100%.

\[
\frac{\text{mass of desired substance}}{\text{total mass of impure substance}} \times 100\%
\]

The selectivity of a reaction is the ratio of desired product formed to undesired product formed. Selectivity is important in separations of mixtures as it is the extent to which a mixture separates out into desired and undesired products. Ideally, selectivity will be close to 1.

\[
\frac{\text{desired product formed}}{\text{undesired product formed}}
\]

Heat of reaction is defined as a unit of measurement to calculate the change in enthalpy of a reaction at constant pressure. Enthalpy is a thermodynamic property that measures the total heat content of the system. It is defined as the total energy of the system plus the product of pressure and volume \((H = U + PV)\). The units of enthalpy are \(\text{kJ/kg}\) and its common abbreviation is \(H\). Simply put, this is a way to measure the amount of energy released or produced in a reaction. The symbol for heat of reaction is \(\Delta H\). The heat of formation is a tabulated value that has been extensively quantified for most pure substances. This is a value
unique to each substance. In order to determine the heat of reaction of a chemical reaction, all the individual heat of formations of each pure reactant must be subtracted from the heat of formation of the pure products. This is defined as Hess’s law. However, for most common reactions, the heat of reaction has been determined and tabulated, therefore Hess’s law is not always needed.

**State vs path functions**

Certain types of chemical engineering measurements and functions rely solely on the state of the system at a given moment in time. These are called state functions. Conversely, other measurements are relative and determined based on the path that was taken in order to achieve this current state. These are called path functions. To give an example, temperature is a state function as the measurement is independent of the previous temperature and how it got there. This is apparent as a glass of water at 25°C is the same temperature as a glass of ice that has now melted to liquid at 25°C. It does not matter how long the liquid has been at this temperature or where it came from, they will both measure as 25°C. Other state functions include density, internal energy, enthalpy, and entropy. Conversely, work is a path function as it depends on the previous state of the system and the changes that have been made. Heat is another example of a path function, as well as the heat of reaction. Work and heat cannot be defined for a certain state as they require initial and final conditions.

**Excel and Plotting**

One of the most basic functions in chemical engineering is excel and plotting. During this semester, this course will cover many of excel’s basic functions and how to use them efficiently for chemical engineering. For more information and plotting examples, reference the excel introductory lab.
A spreadsheet is the word used to describe a workbook in Microsoft Excel. The technical term for each small box on an excel spreadsheet is a cell. Cells can be referenced using a combination of a letter and number. The letters represent to which column the cell belongs and the numbers the rows. Excel is like a large calculator in that it can perform a number of complex mathematical equations. However, better than a calculator, it can also save all the solutions to problems. Equations are typed into excel by clicking on a cell and typing the = sign. This signals to excel that a calculation is about to be performed. Basic mathematical operations are simple to perform in excel. The addition and subtraction signs are the same, but the multiplication sign is * and the division sign is /. Once a numerical value is input into a cell, that cell’s number can then be referenced anywhere else on the page, in any equation by simply clicking on the cell or typing in its referencing number.

Once numerical values have been input into excel, the next step is to create a plot. This can be done with sets of experimental data or values from a given problem. Once the data is input, go to the insert tab at the top of the page. Select the scatter plot option from the plot menu (It will look like a graph of points). This will pop up a blank chart space. Left click on the space to open a menu. Select the “select data” option. This will open a new window where a prompt will ask to add or edit a series. Click the add series button. This will open yet another window which will prompt to add a series title as well as select the x and y values. Click to add the x values and select desired cells. Then repeat this procedure for the y values. This should generate the plot.

The next important step in plot generation is the creation of a trendline. This will create a line of best fit for the data. To do this,

a. Select the chart area
b. Under the design tab on excel, select the add chart element option on the left hand side of the tool bar

c. This will provide a drop down menu of options. This is also where one can select to add axis labels (ALWAYS NECESSARY)

d. For trendlines, select the trendline option.

e. This will drop down an additional menu. Select which option best fits the plotted data.

f. If the trendline equation is needed, one must select **more trendline options** and check the box to display equation on graph.

The most basic trendline, which will be used in this class, is a linear trendline. This will be in the form $y = mx + b$. $X$ is the independent variable and $y$ is the dependent variable. $M$ is the slope of the line which describes how much the independent values vary with a change in $x$. Finally, $b$ is the $y$-intercept of the graph, or where the line crosses the $x$ axis. This type of plotting and trendlines will be necessary for some of the lab work.

There is an option on the trendline menu to display an R-squared value. This is located directly under the display equation on graph option. This is a measurement of goodness of fit of the trendline to the data. It can range from 0 (which is very bad) to 1 (which is ideal).

Over the course of the semester, there may be some data that cannot be classified as linear or fit to a linear trendline. This is quite common for real world scenarios, for example the exponential growth of yeast. The most common non-linear equations that can be put into a linear form by manipulation are logarithms and exponentials. This course will not go into detail on how this linearization is done, but it is a technique used often in the plotting of data in order to create a graph that is easier to analyze.
For example, when tasked with an exponential function, it is necessary to take the natural log, ln, of both sides in order to obtain a linear equation.

\[ Y = A \cdot e^{xB} \]

\[ \ln y = \ln A + xB \]

Exponential growth is a function in which the rate increases more rapidly as the x axis increases (typically as time goes on or size increases). An exponential growth function is half U-shaped in form and is initially very flat but then shoots almost directly up once a specific x value is reached. Yeast growth in fermentation is an exponential growth function as the rate of yeast growth increases more rapidly as the time increases.

Interpolation is a skilled used on charts and tabulated data when the exact value needed is not reported. For example, if the pressure of steam at 503K is needed but the table only reports in multiples of 5, thus 500 and 505K. Here interpolation would be used to obtain the exact value desired. The basic equation used for interpolation is:

\[ x = x_1 + \left[ \frac{T - T_1}{T_2 - T_1} \right] (x_2 - x_1) \]

Where x is the desired value, and T is the desired temperature. T₁ is the lower temperature and T₂ is the higher temperature. X₁ is the known value of x at T₁ and x₂ is the known value of x at T₂. This equation does not have to be used with temperature. It can be used with any 2 tabulated variables that are interrelated.

**Engineering ethics basics**

The engineering world operates on a code of ethics both universal to general human life, but also specific to the science and technology fields. This area of study focuses on
what is expects from engineers both in the products they make and how they are presented to the world. Engineers are responsible for high quality work and cutting edge technology, but also for the safety of anyone using their products and the public. It is important to study past engineering disasters in order to learn from past mistake and ensure that they are not made again in the future. Most disasters occur because people skip checks or choose to take the simpler path. Similarly, mistakes are made and disasters occur when engineers are too afraid to speak up about potential risks.

There are a few key disasters in the chemical engineering field that are typically discussed in every chemical engineering curriculum. These include, Flixborough, BP Texas City, BP Deepwater Horizon, the Challenger and Exxon-Valdez to name a few. This course will discuss one disaster in depth as an in class activity during the semester, but if more information is desired, it is highly recommended that the student conduct further research into these failings.

**Lesson 8: Reactions**

Chemical engineering curriculum relies heavily on chemical reactions. One might ask, what a chemical reaction is and why are they so important? A reaction is anything that rearranges the structure of molecules in order to create new molecules. Basically they take one or more substances and turn them into different ones using the same base elements. Recall that matter cannot be created or destroyed so all molecules or elements that are reactants must also be present in some form as products as well. Chemical reactions are used to generate everything in the universe. All elements exist in their pure form on earth or in space, but in order to create most of the products and chemicals that are used in everyday life, many chemical reactions must be carried out. These reactions are carried out in reactors, as discussed in lesson 7. This can be done on a laboratory/pilot scale or in huge factories.
Reactions can be classified as either reversible or irreversible. As the name implies, a reversible reaction is one that can be returned to its original state. In doing so, this leaves no change to the system or its surroundings. This is basically the equivalent of solving a puzzle and then taking all the pieces apart again. This can be done continually and to any extent. An irreversible reaction, on the other hand, is one that cannot be undone. As soon as this reaction occurs it is permanent and the system or its surroundings are changed. For example, when a system releases heat into the environment. Both of these types of reactions deal with reaction equilibrium. Equilibrium is what causes a process to be reversible or irreversible depending on if it is reactant or product favoring. Processes can have different degrees of reversibility as a result. This is also not a set in stone characteristic as reversibility typically changes with temperature. Some factors that make a process irreversible are friction, unconstrained expansion, mixing, and heat transfer.

One way to measure the efficiency of a reaction or the degree to which a reaction is carried out is extent of reaction. The technical definition of extent of reaction is the degree to which a reaction reaches complete or full conversion of reactants to products. Not all reactions will reach completion, especially if they are extremely reversible. However, extent of reaction is a good measure of how much of the reactants are converted into products. The unit of extent of reaction is a mole. A limiting reactant is typically picked and its conversion followed through the reaction. Then the extent of reaction of the other reactants can then be calculated using the initial reactant as a basis. Extent of reaction is calculated using the stoichiometric ratio of the reactants and products to the limiting reactant. Extent of reaction can be used to calculate the final number of moles of each product and reactant by the formula:

If: \( aA + bB \rightarrow cC + dD \)
Then: \[ N_A = N_{Ao} - \xi \]

\[ N_B = N_{Bo} - \frac{b}{a} \xi \]

\[ N_C = N_{Co} + \frac{c}{a} \xi \]

\[ N_D = N_{Do} + \frac{d}{a} \xi \]

These equations can be used to solve for the final amounts of each substance in a chemical reaction.

Often additional non-reactive substances are added to a reaction in a reactor in order to better control temperature and pressure and avoid explosions. Inerts are gases or other non-reactive substances that have no effect on the kinetics or basics of a chemical reaction. They can be used as system checks as they alter the overall volume of the system. Some common inerts used in chemical engineering are nitrogen gas or a noble gas.

A specific type of reaction that involves the burning of fuels with oxygen is called a combustion reaction. The goal of this type of reaction is to release energy that can be used to heat or power machines. For this type of reaction, oxygen gas must be present. A fire is a very common example of a combustion reaction. Think about smothering a fire, or putting a cap on a candle. What happens? The fire is extinguished. This is because the oxygen supply has been cut off. Combustion reactions are always exothermic, meaning that they release heat. Almost anything organic (made of carbon, hydrogen, and oxygen) will burn or combust. When organics combust, the products are carbon dioxide (CO\(_2\)), water (H\(_2\)O), and of course heat.
Combustion reactions can either be classified as lean or rich. A lean combustion reaction is one that runs on less oxygen than the ideal stoichiometric ratio. Recall that the stoichiometric ratio is calculated by balancing the chemical reaction equation. On the other hand, a rich combustion reaction is one that runs on excess oxygen. A typical outdoor bonfire would be considered a rich combustion reaction as it has an unlimited oxygen supply from the air.

Another common type of reaction is a fermentation reaction. This was discussed in earlier lessons as fermentation is used in the production of beer, wine and spirits. This type of reaction involves yeast in either aerobic or anaerobic conditions. The yeast can produce alcohol from sugars metabolically. As the yeast eats up the sugar, carbon dioxide and alcohol are released. This type of reaction can also occur in bacteria and in the human body when muscles are oxygen starved. This phenomena is the reason that muscles are sore after not working out in a few days; the lactic acid builds up. The chemical reaction equation for the production of ethanol from sugar (glucose) is:

\[ C_6H_{12}O_6 \rightarrow 2 C_2H_5OH + 2 CO_2 \]

Sometimes reactions become too large and give off too much heat and energy. These reactions are hard to control and can often be said to “runaway”. A runaway reaction is defined as a process by which an exothermic reaction goes out of control. The result of runaway reactions, more often than not is an explosion. This is because the energy or heat builds up too much and must be released in some way. The reaction speed will continue to increase until either it runs out of reactants or the reactor pressure gets to be too high and bursts.

Another type of reaction is a biodiesel reaction. This is a reaction in which biodiesel is produced using transesterification and esterification. Esterification is a reaction with
an alcohol and an acid that produces an ester and water. Esters are chemical compounds with multiple oxygens connected to a central carbon group. In a biodiesel reaction, vegetable oil or animal fats and oils are reacted with methanol or ethanol. In this type of reaction, the feed oils must be treated and the water is removed. Acid catalyzed esterification can be used to react the fats with the alcohols in order to produce biodiesel. This is much more environmentally friendly than common gasoline and can be used to power a variety of machines. Typically, recycled oils are used for this process which cuts down on production costs.

Another eco-friendly reaction that is used to produce energy and fuel is the creation of biogas from waste products. Biogas is a mixture of carbon dioxide (CO$_2$) and methane (CH$_4$). It is combusted with oxygen and used in a variety of chemical process either to heat substances or in a gas engine to convert the gas energy to electricity and heat. Anaerobic fermentation or digestion via bacteria of sewage or plant waste as well as human and animal waste can be used to make biogas. Biogas is a renewable fuel that can be substituted for fossil fuels. Biogas engines improve waste management and minimize energy costs.

**Lesson 10: Thermodynamics Basics**

One of the essential topics in chemical engineering is thermodynamics. This is the study of heat and other forms of energy and their relationships to each other. A study of thermodynamics explains why hot items cool off, how motion is turned into power, and how differences in height can create energy.

There are a few basic laws of thermodynamics through which all further studies stem. The zeroth law of thermodynamics is that if 2 bodies (objects) are at the same temperature as a third object, then they are at the same temperature as each other. Basically this means that all
temperature measurements are consistent with each other if in the same units. Recall, this was explained earlier in the temperature section of lesson 2. If something measures 25 degrees, it does not matter where or when it is measured, just that numerical value is always equivalent.

The first law of thermodynamics is one that is already familiar. Recall that energy and matter can neither be created nor destroyed. Energy and matter can take different forms but never be completely eliminated. In every process, the total energy of the universe remains constant. Recall that depending on the system, energy can enter or exit, but it must always go or come from somewhere.

Because of this phenomena, countless systems of equations are able to be solved. This idea can also be extended to solve more complex problems, some of which will be explored in this lesson.

Recall from lesson 7 how to calculate the vapor pressure or saturation pressure of a chemical using the Antione equation.

\[ \log P_{\text{sat}} = A - \frac{B}{T+C} \]

The vapor pressure of a chemical is the pressure at which particles will begin to move from the liquid to the vapor phase at a given temperature. There are a few other ways to calculate vapor pressure. One of these that will also be used in this course are cox charts. Cox charts have all vapor pressure information tabulated in one place. All that needs to be done is to develop a linear equation to relate the vapor pressures. If 2 vapor pressures and temperatures are known, then the slope and intercept of the line can be determined through simple linear analysis. (Consult the excel section for more information on lines and plotting). The linear equation \( y = mx + b \) can be used to solve for the slope and intercept when both \( x \)'s and \( y \)'s are known.
Certain types of chemical engineering problems rely on the principle of humidity or water particles in the vapor phase. These types of problems can be solved in a number of different ways but the most common and easiest way to proceed is to use psychometric charts. This chart depicts many lines that convey the relationship between humidity, temperature, and adiabatic saturation. Humidity is defined as the amount of water vapor in the air at given conditions. The humidity ratio given on the right hand y-axis of the chart is the amount of moisture per amount of dry air. The x-axis of the psychometric chart is the dry bulb temperature. Dry bulb temperature is defined as the regular temperature of the air measured freely in a thermometer. Conversely, the wet bulb temperature is the temperature the air would have if it were cooled to saturation. Saturation means the air is at 100% capacity for water vapor (100% relative humidity). Basically, wet bulb temperature is the temperature reading on the thermometer if it was fully saturated. Wet bulb temperature can be calculated for a given dry bulb temperature by following the humidity ratio line all the way to the 100% saturation curve. This is also depicted on the chart as curved lines. The diagonal lines on the chart are the enthalpy of the water and air mixture.

Relative humidity is calculated as

\[ HR = \frac{P_p}{P^*(T)} \times 100\% \]

Where HR is the relative humidity, Pp is the partial pressure of the water, and P*(T) is the vapor pressure at the given temperature.

When working with gases, often times the partial pressure of each gas is given instead of the mole fraction. This can be used to determine the mole fraction if the total pressure of the system is known. The equation is:
\[ x_a = \frac{p_a}{P} \]

Where \( x_a \) is the mole fraction of substance \( a \), \( p_a \) is the partial pressure of \( a \), and \( P \) is the total system pressure.

The absolute humidity of the system is calculated as the mass of the vapor divided by the mass of the dry gas

\[ H_A = \frac{m_v}{m_g} = \frac{mass \ vapor}{mass \ dry \ gas} \]

The second law of thermodynamics states that the entropy of an isolated system not in equilibrium will tend to rise over time. Entropy is a thermodynamic quantity that represents the degree of disorder in a system. It is a measurement of the system’s inability to convert heat into work. The SI units of entropy are kJ/kg K. Its value is relative to an arbitrary reference state. The common abbreviation for entropy is \( S \).

The second law means that the chaos or instability of a system will always increase in an isolated system. This translates to the fact that it is impossible to have 100% thermodynamic efficiency within systems. Thermodynamic efficiency means the ratio of heat that is turned into usable work.

Finally, the third law of thermodynamics states that as the temperature of a system approaches absolute zero (0K), the entropy of the system also approaches a constant minimum. This means that a system is most stable at lower temperatures.

Recall that enthalpy is a thermodynamic property that measures the total heat content of the system. It is defined as the total energy of the system plus the product of pressure and volume:
\[ H = U + PV \]

It is a useful measurement of the heat and thus energy change within a system. Enthalpy is a point function derived from an assumption of constant pressure.

Enthalpy of certain chemicals at a wide variety of temperatures and pressures can be found readily in literature. In particular for the various forms of water. These tables for water are referred to collectively as steam tables. They typically include the phases: compressed liquid, saturated liquid, saturated vapor, and superheated vapor as well as the temperature, pressure, specific volume, enthalpy, and entropy related to each phase.

Steam tables are useful when working problems that deal with vapor-liquid equilibrium. This is when there is a phase equilibrium with one or more components in a mixture. The most basic VLE system is with just one component. This chemical is present in the vapor phase, the liquid phase, or both, depending on the process conditions.

For a single thermodynamic state, 2 independent properties are needed in order to determine the state. For example, in order to determine if the chemical is a saturated liquid or a compressed liquid, both temperature and pressure are needed. Then the steam table can be referenced for both the compressed liquid and the saturated liquid states to determine which phase meets these specific requirements. Typically, it will be given or determined from previous problem work that a chemical is in a certain state. This would be one independent variable. The other could then be temperature or pressure. Typical steam tables are organized by phase and increasing pressure. This means, for example, that the pressure will increase over a certain interval all within the superheated phase.
If the necessary temperature or pressure is not explicitly stated in the table, but there are values smaller and larger than the desired condition, interpolation may be used to determine the specific values needed. Recall the interpolation method from lesson 7. For example, if one is looking for the conditions at 7 kPa but the table only shows 5 kPa and 10 kPa, then one can interpolate to get the 7 kPa properties.

For each chemical, phase diagrams can also be generated in order to determine the relationship among variables. The three common diagrams are pressure-volume with constant temperature, pressure-temperature at constant volume and finally temperature-volume at constant pressure. These diagrams help to depict the trends such as pressure decreases as volume increases when temperature is held constant. Similarly, pressure increases with temperature at constant volume. Finally, temperature increases with volume at constant pressure. These diagrams also help to determine which phase the chemical is in under given conditions. If the point is outside and to the right of the line on the diagram, the chemical is a super-heated vapor. If inside, it is a saturated liquid-vapor mixture. Finally, if it is outside and to the left of the diagram, it is a compressed liquid.

Before continuing further into thermodynamic systems, it is necessary to define a few terms that are used to describe systems.

Isothermal- the temperature of the system is constant. This can be accomplished with a heating or cooling jacket.

Isobaric- the pressure of the system is constant. The pressure does not change with time or changes in any other variable.

Isochoric – the volume of the system is constant.
Isentropic- the entropy of the system remains constant. It is also adiabatic and reversible.

Isenthalpic- the enthalpy of the system remains constant.

Adiabatic- no energy enters or leaves the system.

Exothermic- (recall from previous reactions lesson) the reaction gives off energy, typically in the form of heat as a product of the reaction

Endothermic- the reaction takes in energy, typically in the form of heat, meaning it is a reactant of the reaction

**Intro to non-ideal gases**

In lesson 7, the ideal gas law was introduced. This is used in any systems containing gases to predict behavior. The shortcoming of the ideal gas law, \( PV = nRT \), is that it only applies under ideal conditions. Recall that this means that the density of the gas is low and that there are weak intermolecular forces between particles. Unfortunately, most real world gases do not meet these requirements so they are deemed non-ideal. Luckily, there are a few correlations and equations that can be used in order to predict these non-ideal gases behavior.

Algebraic equations that predict the behavior of gases, both ideal and non-ideal, are called equations of state (EOS). They help to determine the temperature, volume, or pressure of a given gas when 2/3 of these characteristics are known. For example, the ideal gas law is an EOS for ideal gases. There are many equations of state used throughout chemical engineering, even for very complicated systems. Most of these began as expansions of the ideal gas law in order to meet the desired system characteristics or substances. Equations of state rely on rigorously calculated constants that are specific for a given scenario of characteristics or
substances. These constants, often referred to as parameters, are developed through experimentation, observation, and data collection. The data is then fit to parameters to give lines of best fit. This is how EOS are developed. These parameters can be unique for each individual chemical or for specific types of situations. Two very common equations of state are the Soave and the Peng-Robinson. These are a step above the ideal gas law but are still fairly basic in the grand scheme of EOS. These were developed as extensions of the ideal gas law to apply to non-ideal situations. The Peng-Robinson equation is shown below:

$$P = \frac{RT}{V - b} - \frac{a \alpha(T)}{V(V + b) + b(V - b)}$$

Where a and b are experimentally determined parameters unique to each chemical.

**Gas-liquid phase reactions (VLE)**

Equations of State are useful for gas-liquid phase reactions as they help supply more information in order to solve the problem. A gas-liquid phase reaction is, just as the name suggests, a reaction that takes place in both the gas and liquid phases. This is where equilibrium is achieved between the vapor and liquid phases of a chemical or mixture. Thus this type of reaction is often referred to as a vapor-liquid equilibrium (VLE) problem. Typically, some basic information from the system will be given. The pressure, temperature, or composition of the system in either the vapor or liquid phase will then be solved for.

For the reaction of one pure component, it is fairly simple to solve gas-liquid systems. The pure component will be at equilibrium between its vapor and liquid phases at its saturation pressure. Recall from previous lessons that the saturation pressure of a pure component can be calculated using the antoine equation or cox charts if the system temperature
is known. Similarly, the temperature can be determined if the saturation pressure is known. If there is only one component in the system, it is not necessary to determine the composition (mole or mass fractions) of the system as it will be 1.0 in both phases. The specific volume of the gas and liquid as well as the entropy and enthalpy can be determined using steam tables for the given liquid. This is most commonly tabulated for water systems.

The problem becomes a bit more complicated with multiple components. This type of system contains at least 2 unique components that are in both the gas and liquid phases. It is necessary to determine the saturation pressure of all the components at the given system temperature. Recall, that Raoult’s law can be used to determine the composition of the vapor or liquid phases if the other is known. Raoult’s law states,

$$yP = xP_{sat}$$

Where y is the vapor mole fraction, x is the liquid mole fraction, P is the system pressure and $P_{sat}$ is the vapor pressure. This analysis can be done for all components in the system after the vapor pressure is calculated. For a 2 component system, recall that the mole fractions must add up to 1.0. Therefore, once the x and y for one component are known, one can subtract these from 1.0 to determine the mole fractions of the remaining component. Typically, the temperature of the system will be given and the vapor pressures can be calculated.

For multicomponent systems, it is also important to note that the more volatile component (the one with a lower boiling point) will be more abundant in the vapor phase than the liquid. The opposite holds true for the less volatile component; it will be more abundant in the liquid phase and less likely to evaporate. Multi-component systems are used in the production of alcohol via the distillation of water and ethanol. The more valuable component, in
this case the alcohol, is transferred from the liquid to the gas phase and harvested in another container. This process can be done for most VLE systems.

Azeotropes are a special class of multi-component VLE system. They are very strong deviations from ideality in which the composition of the boiling liquid is the same as the condensing vapor at a given temperature. These are especially troublesome in distillation as distillation relies on the difference in boiling points of the components. However, azeotropes boil at one constant temperature and, as previously stated, the vapor and liquid compositions are the same. This means that it is very difficult to achieve any level of separation through distillation. In the case of azeotropes, another separation technique must be used to separate the components.

Lesson 11: Thermodynamic applications

Thermodynamic efficiency is a measure of how much energy is converted to usable work. This is a ratio of usable work to theoretically created energy. The units of thermodynamic efficiency are %. It is calculated as the amount of usable work out divided by the total amount of required work or energy into the system or cycle.

The next few cycles that will be discussed deal with the second law of thermodynamics: the efficiency of a system cannot be 100%. According to kelvin-plank, it is impossible to construct a device that can operate in a cycle and produce no effect other than lifting a weight. This means that heat or energy must be exchanged while lifting the weight.

A Carnot cycle was developed by a French engineer, Carnot. It is a heat engine that expresses the fundamentals of the second law. A Carnot cycle consists of a pump, a high temperature boiler, a turbine that exchanges heat and motion for work, and a condenser of low temperature. Both the condenser and boiler exchange heat with the surroundings. The boiler is an
isothermal heat addition in an adiabatic expansion process. The condenser is an isothermal heat rejection. The pump is an adiabatic compression. Each process is reversible in a Carnot cycle.

Since the Carnot cycle is reversible at each step, the whole cycle is also considered reversible. The reverse of a Carnot cycle is a refrigeration cycle. In this case, there is a compressor, evaporator, pump, and condenser. The first step is an isothermal heat transfer process. Followed by a reversible adiabatic process that is also isentropic. Next, an isothermal heat transfer. Then finally an isentropic process.

Internal combustion engines have controlled combustion reactions (recall from lesson 8) that drive a piston to create mechanical work. These are used in cars and house heating. The combustion of fuel such as gasoline or biofuels occurs with air as the oxidizer. This is done in a specific chamber and can then be converted into mechanical work via the expansion of a high temperature or pressure gas in a piston system. This type of engine was created by Nikolaus Otto and resembles the modern engines of today. The combustion is typically intermittent. This is seen in 4 or 2-stroke piston engines.

The Otto cycle is used to simulate the spark ignition internal combustion engine. It was a precursor to the internal combustion engine that is seen today. The Otto cycle consists of a piston that moves from bottom dead center to top dead center over the course of the expansion and compression processes. The process contains a compression step that is adiabatic and isentropic. Next is a combustion step that is isochoric but generates heat. Then comes an expansion process that is adiabatic and isentropic. Finally, there is a heat rejection step where volume is again held constant but the heat decreases. The piston moves during the expansion step and falls back to BDC during the compression step.
The diesel cycle, is similar to the Otto cycle with a few differences. It is a combustion process as well that consists of an internal combustion engine. The fuel is ignited during the compression stage of the air in the combustion chamber. Recall that the Otto cycle ignites the fuel-air mixture with a spark plug. Diesel engines are used in cars, planes, power generation and some trains. The Diesel system runs on the assumption of constant pressure whereas the Otto cycle assumes constant volume (except in the expansion and compression phases). This process consists of an isentropic compression of fluid followed by a reversible heating that is isobaric. Next is an isentropic expansion. Finally, there is a constant pressure cooling step. The Diesel cycle converts heat into work as does the Otto cycle. The usable work is produced in the adiabatic expansion step. This is where heat is transferred into usable work by the engine.

**Lesson 12: Distillation and other Separation Techniques**

One of the most important unit processes in chemical engineering is the separation of chemical compounds. This is where the products from a chemical reaction are split into usable, sellable products. In a chemical process, after the reactor, the products and any unreacted reactants are all mixed together in one process stream. The goal of the subsequent separation steps is to separate the desired or valuable chemicals from the waste products. The separation apparatus will often also separate the unused reactants to be fed back to the reactor as recycle. Recall that recycle helps to reduce raw material costs as well as keep feed ratios constant. Separation processes and be uni-step or multi-step depending on the degree of difficulty of the separation. There are many different techniques that can be used for separation depending on the type of chemicals involved and their properties.
One of the most important types of separation is distillation. Recall that distillation is involved in the production of alcoholic spirits. It is the post-fermentation step used to increase the alcohol content. This is done by distilling the alcohol from the water to create a purer concentration. Distillation is also used in the production of gasoline and other oil products. A series of distillation columns are used to separate the heavy hydrocarbons from the lighter ones. The lighter hydrocarbons are used for the production of gasoline, kerosene, motor oil, and liquefied natural gas while the heavier hydrocarbons are either cracked down to create lighter hydrocarbons or used for the production of diesel. Distillation columns are used in a variety of other applications as well, but these are the most common and relate to products that are used daily. Some other examples of distilled products are pharmaceuticals and liquefied air.

Recall that distillation operates on the principle of different boiling points. The feed is fed into the column as a liquid and is heated to the boiling point of the more volatile component. The more volatile component will evaporate more quickly. This is called the light key and is found in abundance at the top of the tower. The less volatile key will remain in the liquid phase at the bottom of the tower. This is called the heavy key. Selectivity plays a large role here because if the two components are very close in boiling point, their selectivity will be low and a large separation will not be achieved via distillation. This is when other separation tactics may be needed.

During distillation the inlet is typically a liquid and is fed in at a specific height on the column. This feed tray location is determined via a series of complex optimization equations that determine which tray is the optimal feed tray. There are a unique number of trays in each distillation column. This is also determined via rigorous equations that decide the number of equilibrium stages needed for proper separation. Vapor liquid equilibrium is achieved at each
stage on the distillation column. Recall the process of VLE from lesson 10. McCabe-Thiele diagrams are used to determine the optimum reflux ratio, compositions, and feed stage. At the top of the distillation column, the vapor is fed into a condenser in order to condense it back into liquid that can be refed into the column or pumped out as product. After the condenser, the reflux is fed into a reflux drum where it is held. It is then pumped back into the tower or pumped out as product. The amount released as product vs returned to the tower is called the reflux ratio.

\[ r = \frac{\text{product released out}}{\text{distillate returned to column}} \]

Where \( r \) is the reflux ratio. At the bottom of the tower, the liquid is fed into a reboiler. This will heat the liquid into a vapor-liquid mix that can either be refed into the column or released as a finished product.

Typical distillation columns, such as those found in oil refineries are run continuously. This means that feed is constantly being added and products removed from the system. The only time these columns are shut down is for cleaning, regular maintenance, or in the case of a disaster. Continuous distillation is economically beneficial and safer for large scale operations as the most dangerous periods for columns are in the transient phase (either during start up or shut down). This is the most likely time for a disaster. For smaller scale operations, however, batch distillation can be used. This is typically done for laboratory scale production or in the pharmaceutical industry. This is also used in many small scale breweries. Similarly, batch distillation is how moonshine is created and other “home distilleries”. One of the labs in this course is an experiment that deals with batch distillation. In batch distillation, a set amount of feed stock is used and no more feed is fed in after the initial step. A pot containing a mixture of 2
liquids is boiled. The vapors are collected and cooled, resulting in a higher concentration product with more of the lower-boiling point (more volatile) component.

When the boiling points of the mixture components are too similar, as stated before, it is necessary to explore other forms of separation. These include:

**Adsorption:** Adsorption relies on the principle of adhesion of certain molecules to a surface, the adsorbent. There are specific surfaces used in this process due to their large void fractions, allowing many molecules to adsorb to it. Only certain molecules will adsorb to specific surfaces, thus allowing the rest of the fluid to pass though. Adsorption is a surface based process where a film of adsorbate is created on the surface of the adsorbent. It is an exothermic process that’s rate increases steadily until equilibrium. Equilibrium is achieved when the surface is completely saturated with the adsorbed molecules. Adsorption is used in synthetic resin, water purification, the pharmaceutical industry, and biomedical devices.

**Absorption:** Absorption is a process where a fluid is dissolved by a liquid or a solid. This is the absorbent. There is a transfer of one of more components from the gas phase to the liquid phase. Absorption occurs in the bulk of the fluid. It is an endothermic process that occurs at a uniform rate. This is used to separate gas mixtures, remove impurities, and/or recover valuable chemicals. Absorption is used in space cooling, ice production, and the carbonation of beverages.

**Stripping:** Stripping is a physical separation process where a liquid or vapor stream removes one of more components from a mixture. It is basically the opposite of an absorption operation. Stripping removes an absorbed solute from a solvent. Typically, the stripping fluid flows counter current to the mixture. This typically takes place in a packed bed or tray column.
Extraction: Extraction is when a mixture is brought into contact with a solvent in which only the desired substance is soluble, but the other components are insoluble. The principle of extraction is that 2 phases that do not mix are used to separate a substance from one phase to another. This is typically done using an aqueous and an organic phase, which can then be separated via a separatory funnel.

Membrane: A membrane separation is one in which fluid is flowed through a semi porous membrane where only certain particles are able to pass through the membrane wall. This is usually dependent on pore size of the membrane and the size of the molecules trying to pass through. The smaller molecules will be able to move through the walls of the membrane while the larger ones will not. This type of separation relies on pressure drop through the walls as the driving force for the separation.

Lesson 13: Introduction to Fluid Mechanics

Fluid mechanics is a branch of chemical engineering that deals with fluids; their pressure, flow, and energy among other characteristics. The same underlying assumption that energy and mass cannot be created or destroyed is key for the study of fluids, especially those in motion. Fluids deform and take the shape of their containers. Fluids can be gases or liquids, but this section will focus mainly on liquids. Recall that density is mass/volume and is constant for each chemical under specific conditions. Similarly, specific gravity is the ratio of the chemical’s density to that of water or another known standard.

When working fluids problems, as well as any other problems in engineering, it is necessary to establish a control volume. This defines the boundaries of the system in question. Setting the control volume helps to better identify what mass or energy is leaving the system and
draw clear lines of when, where, and how this occurs. A control volume is a set amount of space for a system within the larger universe of space. It can be still or in motion with the fluid, for example a particle.

Shearing stress is the stress or pressure developed within a fluid due to a force on a specific area. This occurs often as fluids flow through tubes. It is defined as force divided by area and its symbol is $\tau$. The units of shearing stress are $F/L^2$ (force per length squared). Some typically units are newton/ meters$^2$ or pounds force/ feet$^2$. It is the tangential force on a surface.

Shear strain rate is the rate of change of velocity of the fluid over a distance $y$. Its symbol is $\gamma$ and its units are Time$^{-1}$. Shear strain is calculated using the equation $\gamma = \frac{du}{dy}$. The direction in which the velocity changes is perpendicular to the direction of the velocity.

Shearing stress can also be used to help classify fluids as either non-Newtonian or Newtonian. A Newtonian fluid is one that’s shearing stress is linearly related to its strain rate. This means as stress is increased, strain displays a proportional response (either an increase or decrease). Newtonian fluids are the simplest models for fluid flow as their forces for stress and strain are uniform throughout. This means that viscosity is only dependent on temperature. Examples of Newtonian fluids are water, honey, and organic solvents. Non-Newtonian fluids, on the other hand, have a viscosity that is dependent on shearing rate. There is no direct correlation to sheering rate and stress. This can vary in each fluid and often with time. Some examples of non-Newtonian fluids are ketchup, toothpaste, paint and blood.

Viscosity is a measure of the fluidity of the fluid. It is a quantifiable measurement of the thickness or stickiness of a fluid which is due to internal friction. Put simply, viscosity is a measure of the fluid’s resistance to deformity (or shear stress). For example, water is
significantly less viscous than honey. The units of viscosity are force time per length squared (FT/L$^2$) depending on the system of measurement used. A common unit is poise. Viscosity is often calculated or defined as the rate of shearing stress to shear rate. The viscosity of liquids will typically decrease with an increase in temperature, whereas, that of gases will increase with an increase in temperature. The symbol for viscosity is $\mu$.

Some additional properties of fluids that have been discussed in previous lessons are pressure, absolute and gauge pressure, vapor pressure, and area.

**Fluid Statics**

The first area of fluid mechanics that will be discussed is statics. This is the study of fluids either at rest or in such a manner that there is no relative motion between adjacent particles. In these cases, there is no shearing stress, only pressure acting on a given point with the fluid of interest. According to Pascal’s law, the pressure at a point in a fluid at rest, or in motion, is independent of direction as long as there is no shearing stress present. This means that if pressure is read at the same point then it is the same.

Pressure varies with depth for an incompressible fluid. The pressure will increase as one goes deeper into a fluid. Horizontal motion has no effect as long as it is still at the same depth. The change in pressure of a fluid as depth or height is varied is given as:

$$\Delta P = P_2 - P_1 = -\rho g \Delta z$$
Where $\Delta P$ is the change in pressure, $P_2$ is pressure 2, $P_1$ is pressure 1, $\rho$ is the fluid density, $g$ is the gravitational acceleration, and $\Delta z$ is the change in depth.

Once the basics of how to calculate the pressure change over a depth change is understood, more advanced fluid statics calculations can be performed. For example, hydrostatic forces on a plane surface. Basically this explains the characteristics of forces on a submerged planar surface. These kinds of calculations are important in the design of dams, ships and fluid storage tanks. The force that will be examined is perpendicular to the surface of the plane as there is no shearing stress. Recall that the pressure of a fluid can be calculated using the equation $\rho gh$ where $h$ is the height below the surface. Pressure is simply force divided by area, so if the calculated pressure is multiplied by the area of the surface then the force of the fluid can be determined.

$$F = \rho g \Delta z A$$

The $A$ here is the total surface area of the planar surface in question.

*Note: there is a more detailed calculation that can be used to determine the exact location of the resultant force of the liquid on a planar surface. This involves determining the centroid of the force on the planar surface which is beyond the scope of this introductory class. However, it is necessary to note that the force being calculated is the force at the bottom of the surface (at the given depth) not the force at every point above this.

Manometers are devices that use vertical or inclined liquid columns to measure the pressure or pressure difference of a fluid. Their equation is quite similar to that of a pressure drop, but the results are on a much smaller scale as the height component will be quite small.

$$P_A = P_o - \rho g \Delta z$$
Where \( P_A \) is the absolute pressure and \( P_o \) is the atmospheric pressure at the given conditions. A monometer is a very simple yet effective way to measure the pressure of a system.

**Fluid Dynamics**

The next subject that will be studied in fluid mechanics is fluid dynamics. This is the study of fluids in motion. In these cases, the net force is not zero as there is velocity and acceleration. To begin, the Bernoulli equation will be examined. Again this is a representation of the continuity equation in which no matter or energy is created or destroyed.

The simplest case for examination is the motion of the fluid along one specific streamline. A streamline is the path followed by a particle during fluid flow. There are a few essential assumptions for this case that include: the flow is steady, viscous effects are negligible, the flow is incompressible, and the equation is only valid along one streamline.

\[
\frac{p}{\rho} + \frac{1}{2}V^2 + gz = \text{constant}
\]

Where \( P \) is pressure, \( \rho \) is density, \( V \) is velocity, \( g \) is gravitational acceleration and \( z \) is height. Note that this equation is equal to a constant. This will be the same constant value at every point on the streamline. The values on the left hand side for each term may vary, but they will always sum to the same constant value. Using this logic,

\[
\frac{p_1}{\rho} + \frac{1}{2}V_1^2 + gz_1 = \frac{p_2}{\rho} + \frac{1}{2}V_2^2 + gz_2
\]

This can then be simplified to,

\[
\frac{p_1 - p_2}{\rho} + \frac{1}{2}(V_1^2 - V_2^2) + g(z_1 - z_2) = 0
\]
This allows us to solve for any desired variable when the rest are provided or readily available.

The physical meaning of the first term in the equation is the work done by the pressure force. The physical meaning of the second term is the change in kinetic energy. Finally, the physical meaning of the third term is the work done by gravity. There is no change in total energy, only in each individual term. The change in one term, thus, causes a change in the others. It is common for some of these terms to cancel out, as it the case with constant height or velocity. The pressure can often be calculated using the equation from fluid statics.

Reynold’s number is a dimensionless number that relates the characteristic flow of a fluid to its density, velocity, pipe diameter, and viscosity. It is technically referred to as the ratio of internal forces to viscous forces. The Reynold’s number is used in fluid mechanics to predict flow patterns. Historically, it was developed by Osbourne Reynolds in the 1880s during an experiment with dyes. It is defined as

\[
Re = \frac{\rho vD}{\mu}
\]

Where Re is Reynold’s number, \(\rho\) is the fluid’s density, \(v\) is the average velocity, \(D\) is the pipe diameter, and \(\mu\) is the viscosity. For flow inside a tube, if the Reynold’s number is below 2100 then the flow is considered laminar. If the calculated Reynold’s number is greater than 4000 then the flow is turbulent. Any Reynold’s numbers in between these two consider the flow to be within the transitional range. For fully developed flow (not neat the end of beginning of the pipe) in a horizontal pipe, the driving force of the flow is a pressure difference.
Laminar vs turbulent flows

Fluid flow in a pipe can be characterized in a variety of different ways, but the most basic distinction is between the type of flow: either laminar or turbulent. Laminar is a one-dimensional flow that is orderly and occurs at low velocities. The particles in laminar flow move in straight lines. Because of this, simple mathematical analysis is possible for laminar flows. Turbulent flow is unpredictable and occurs at high velocities. It is a 3-dimensional flow as particles are jumping streamlines as they flow, causing their paths to be irregular. Because of all of this, mathematical analysis is difficult for turbulent flow.

Friction factor

Until now, essentially only ideal fluids have been discussed. There is no energy losses due to friction or heat in these types of fluids. However, because fluids are viscous, energy can be lost in the flow due to the friction of the flow against the tube. The effects of friction are typically seen as a pressure drop or loss. Because of this, a friction factor can be used to estimate the pressure drop for flow in a pipe of a given surface roughness. For laminar flow, the friction factor can be simplified to

\[ f_D = \frac{64}{Re} \]

For turbulent flow, on the other hand, this relationship becomes more complex and has been calculated and published in what is called a moody chart. The friction factor and force is proportional to the Reynolds number and the relative roughness. This chart compares the Reynolds’s number to roughness of the pipe divided by diameter to the friction factor. The Reynolds’s number is on the x-axis, the relative roughness on the right-hand y-axis and the
friction factor on the left-hand y-axis. The use of the moody chart will not be required for this class, but a basic understanding of what it is and when it is used is expected.

A dimensionless number is one in which all of the units cancel each other out. There are no physical dimensions for these types of numbers. Some examples of dimensionless numbers include the Reynold’s number and the Biot number. Other arrangement of units can be used to develop dimensionless numbers that can then be used to create models or simulations to scale up to real size or speed. This is exemplified in the Buckingham Pi theorem. This theorem is beyond the scope of this class, but it is worth noting another case when dimensionless numbers can be useful.

Lesson 14: Heat Transfer Methods

Moving forward in to the higher level concepts within chemical engineering, a transition is made from fluids to heat. There are many similarities between the flow of fluid and heat. Additionally, heat transfer problems typically involve the flow of fluids through pipes or over surfaces. For heat transfer purposes, it is necessary to classify flow as either internal, through a pipe, or external, over a surface. For the purpose of this class, the discussion of heat transfer and exchangers will be kept to a high level understanding instead of all the minor details and calculations.

As stated in lesson 6, heat is a form of energy. It is also commonly used to describe the temperature of an object. However, this is not the technical meaning of heat, but simply a reference to an object’s physical temperature. Temperature and heat are related but not interchangeable.
Consider the example of a hot cup of coffee being placed on the table of a room at room temperature. Some minutes later, one can observe that the coffee has now cooled down. The room doesn’t feel any hotter, so where did the heat go? This is true that one may not perceive the change in temperature of the room, but this does not mean that heat was not transferred. Energy is always conserved. Therefore, if the coffee feels colder, i.e. lost heat and temperature, then the room must have gained heat. The room, however, is a large control volume so the heat can be distributed throughout the whole room instead of just within the small coffee cup. A lower temperature in the coffee is a noticeable effect of the average kinetic energy of the coffee particles decreasing (loosing heat).

Heat can also be defined as the transfer of energy from a hotter object to a colder one. Heat will always flow hot to cold. Temperature gradients are always the driving force of heat transfer. All other forms of energy can be converted into heat, just as heat can be converted into other forms of energy. For example, kinetic energy can be converted into heat via friction that gives off thermal energy as a result of decreasing velocity. Electrical energy is converted to heat when in space heaters or even simple lights in one’s home. Think about a standard light bulb that has been on for a while. It is very hot to the touch. Finally, chemical energy from food is converted within our bodies into heat to keep us warm. The unit for heat is joules or btu in the SI and English system respectively. The standard unit for the rate of heat transfer is the Watt or joule per second.

Heat can be transferred in 3 methods. The first is via convection. This is the type of heat transfer that occurs via the direct contact of colder molecules or particles with hotter ones. For convection to occur, the objects must be touching. Conduction occurs due to the collision of molecules. The faster moving molecules contact the slower moving ones and give
them some of their energy. When the fast moving particles collide with a boundary or wall they cause the wall’s particles to vibrate as well, thus transferring energy. There is no transfer of matter between the touching objects, only thermal energy. This type of heat transfer typically occurs within solids. Some substances conduct heat better than others. For example, metals are great conductors whereas plastics are poor conductors. This deals with the degree of thermal conductivity, a unique property of each substance. The equation for conductive heat transfer is:

\[
\dot{Q} = \frac{\kappa A (T_h - T_c)}{d}
\]

Where \(\dot{Q}\) is the heat transfer rate, \(\kappa\) is the heat transfer coefficient, \(A\) is the area of heat transfer, \(T_h\) is the hotter temperature, \(T_c\) is the colder temperature, and \(d\) is the distance or thickness of the boarder.

The second method of heat transfer is convection. This type of transfer takes place when warmer areas of a fluid rise to colder ones. This is known as the mass movement of the fluid. When the hot fluid moves, the colder fluid can take its place. Convection is accomplished via a circulation pattern where the hot and cold fluids are constantly moving around within the media. The equation for heat of convection originates from Newton’s law of cooling, it states:

\[
\dot{Q} = hA(T_w - T_\infty)
\]

Where \(h\) is the convective heat transfer coefficient, \(T_w\) is the temperature of the fluid and \(T_\infty\) is the temperature of the surroundings.

The third and final method if heat transfer is radiation. This method, unlike the previous 2, does not require a medium or any contact between the heat source and the object being heated. Heat can be transferred through empty space via radiation and electromagnetic
waves. The most common form of radiation is the sun’s rays traveling across space to heat the earth. There is obviously no contact between the sun and the earth and a large distance separates the two, yet via radiation the sun is able to heat the earth. The radiative heat transfer equation is

\[ \dot{Q} = \epsilon \sigma (T_s^4 - T_{\text{sur}}^4)A \]

Where \( \sigma \) is the Stefan-Boltzmann constant, \( 5.6703 \times 10^{-8} \), \( T_s \) is the absolute temperature in kelvin of the surface, \( T_{\text{sur}} \) is the absolute temperature of the surroundings, \( \epsilon \) is the power emitted by the object, and A is the area of the emitting body.

Heat exchangers allow two process streams to exchange energy, thermal energy to be exact. The hot flow gets cooled down by heat transfer to the colder flow. Liquid-air heat exchangers are often called radiators. Liquid-Liquid heat exchangers are often run in counter current fashion. Counter current means that the inlet streams enter from opposite sides of the exchanger in order to maximize heat transfer. Exchangers can also run co-currently if need be. This means that both inlets enter from the same side of the exchanger. The most common type of exchanger for a plant is a shell in tube or floating head exchanger. Exchangers typically have an input steam of pure water or steam that is used to either heat or cool the system depending on what is required. The water can enter as high pressure steam, medium pressure steam, low pressure steam, boiler feed water, or cooling water. The different between these inputs is the pressure and phase of the water. The heat transfer equation for a heat exchanger is:

\[ \dot{Q} = UA(\Delta T)_{\text{LMTD}} \]

Where \( U \) is the heat transfer coefficient, \( A \) is the heat transfer area, and \( \Delta T_{\text{LMTD}} \) is defined as

\[ (\Delta T)_{\text{LMTD}} = \frac{(\Delta T)_{\text{in}} - (\Delta T)_{\text{out}}}{\ln((\Delta T)_{\text{in}})} \]
Where $(\Delta T)_{in}$ is the temperature difference between the 2 inlet fluids and $(\Delta T)_{out}$ is the temperature difference in the 2 outlet fluids. Ln in the natural log operation.

**Lesson 15: Elements of Chemical Design Processes**

This last chapter will serve as a big picture sort of wrap up to the course and the study of chemical engineering overall. In this chapter, everything that has been discussed throughout the course will be brought together to see how large scale chemical processes are created.

This will begin with a discussion of static vs dynamic systems. A system in static is unmoving whereas a dynamic system is in motion. Recall this applied to fluid mechanics. This can also be applied to batch reactors vs continuous ones. A batch reaction is static as once the reactants have been fed in there is no flow in or out. Whereas, a continuous process has the flow in and out of reactants and products respectively. Similarly, a reaction in static equilibrium is irreversible whereas a reaction in dynamic equilibrium is reversible.

A similar classification to static vs dynamic is steady-state vs transient. Ideally, all problems and systems would be in steady state, but this often requires a transient period to achieve this. Steady state means that the variables that define a system do not change with time. Recently observed behavior will continue to be so. On the other hand, transient problems contain variables that change with time. Most engineering problems that one can encounter will be steady state. Often when engineers are developing systems, they will work with the assumption that everything is steady state then alter those assumptions for specific start up and shut down as need be. When a system is steady state, as stated before, nothing changes with time. This is typically how most energy transfer problems are able to be simplified. The change in energy in
the system over time is zero. The same idea applies for mass transfer as well. This however does not apply for transient problems. This is why transient systems are mathematically more complicated than steady state; because there is an additional variable.

In most large scale chemical processes it is necessary to have control systems in place. These systems monitor the temperature, pressure, volume, and/or other characteristics of the system or a specific process to ensure they are still within specification. If a variable is out of its allowable range, then an alarm will go off or the system will readjust itself accordingly, depending on what kind of control system is set up. Control systems vary in complexity from a simple control open/close valve to relieve pressure to a complex system that monitors the smallest temperature change and adjusts the temperature of the cooling water accordingly. The two most basic types of control systems are feedforward and a feedback. Feedforward is one in which the disturbance is measured and the valve is adjusted accordingly. Similarly, a feedback system relies on information ahead of it in the process. It measures the output and relays this information back to the controller. The controller in turn then adjusts an inlet valve accordingly. More complex systems are available, but there are the two most basic loops.

Some essential pieces of equipment in chemical processing systems that have not been previously discussed are pumps and compressors. Pumps are mechanical devices that run on electricity and power. They are used to increase the pressure of liquids and move them from place to place or unit to unit. Pumps turn electrical energy (most commonly) into mechanical energy by the movement of fluids. They are used in a variety of applications such as water-cooling and filtration, the car industry, the oil and natural gas industry, and the medical industry to name a few. Some common types of pumps include the positive displacement pump and the centrifugal pump. A positive displacement pump functions by trapping an amount of the fluid
being pumped and forcing that trapped volume into a displacement pipe. They are considered constant flow machines. Centrifugal pumps use an impeller to turn rotational kinetic energy into hydrodynamic energy. This results in an increase in the pressure of the fluid and/or its flow rate.

Compressors are pumps for vapors. Liquids cannot be used in compressors as they are generally considered to be incompressible. Compressors are mechanical devices that convert electrical energy into mechanical energy. They are used to compress or decrease the volume of a gas. As explained by the ideal gas law, when the volume of a gas decreases, the pressure increases. Compressors, like pumps, are used to move fluids through pipes.

The big picture of how all the unit processes fit together to create a complete plant can now be studied. This will combine a knowledge of machinery and vocabulary from the previous lessons in order to obtain big picture ideas of what a chemical processing plant is. There are 5 major sections of processes in a typical engineering plant. They consist of: reactor feed preparation, reactor, separator feed preparation, separator, and finally recycle structure.

First is the reactor feed preparation section. This typically consists of the flow of the reactants from their storage tanks all the way to the reactor. This is the section where the reactants are brought up to reaction temperature and pressure. This is accomplished via a system of heat exchangers, pumps, and compressors. The reactants are stored in storage tanks or vessels at a given temperature and pressure. They must be brought to a specific reaction temperature and pressure in order for the reaction to be carried out. Recall that heat exchangers can either heat or cool the fluid. Also recall that pumps are used to pressurize and move liquids whereas compressors are used to pressurize and move gases.
The reactor step is fairly self-explanatory. This is the section where the reaction takes place and the products are created. The reactants flow in from the reactor feed prep at a specific temperature and pressure. The reaction is then carried out in one or multiple reactors. The type, size, and number of reactors depend on the size of the reaction, amount of fluid, and reaction kinetics. Some typical types of reactors are batch reactor, conversion reactor, continuously stirred tank reactor, packed bed reactor, and plug flow reactor. These are selected based on the desired end result of the reactor, for example the desired conversion.

Once the reaction step is completed, the products and unused reactants flow into the separator feed preparation section. Similar to the reactor feed prep section, this section’s objective is to bring the streams to separation temperature and pressure. This is the T and P necessary for the separation to occur, typically in a distillation column. This temperature and pressure change is again achieved through a series of heat exchangers, pumps and compressors.

After the separation feed prep step comes the separation process section. In this section, the pure products are separated from the waste and unused reactants. Recall from lesson 13 that there is a variety of different separation techniques that can be used. This is determined on a system by system basis depending on what chemicals are present. The most common separation apparatus is a distillation column. The separation section can also contain multiple pieces of separation equipment for example, a distillation column followed by a stripper. All of this is highly dependent on the system.

The final section in a chemical process is the recycle structure. This typically emerges from the separation section as the recycle structure deals with the unused reactants. These are separated from the products in the separation step and then sent through the recycle system. This system typically consists of heat exchangers, pumps or compressors that bring the
fluid to reaction feed temperature and pressure again. This is because the unused reactants will be fed back into the reactor to be reused in the reaction.

Recall from lesson 1, a brewery works in the same fashion as a chemical plant. The reactor feed section is all the steps prior to fermentation; from the harvesting to the malting to the creating of the wort. The reaction step is the fermentation via yeast. A separation feed prep step may be pumping the beer to a filter, which is the separation step. This separation step removes the particles left over from the fermentation from the beer. This is commonly done with a plate and frame filtration apparatus. There is typically no recycle step in the brewing process unless the yeast is reused.

The whiskey production process and subsequent distilling process functions even more similarly to a chemical plant. As with beer, the reactor feed prep is everything from harvesting of the grains to creating the wort. The reaction is the fermentation performed by the yeast. The separator feed prep is the pumping and heating that occurs to move the fermentation products of water and alcohol and CO$_2$ to the distillation column or pot still. This involves making sure that the fluid is at the proper temperature and pressure for distillation. Next, the separation section, as one could guess, is the actual distillation. This is where the valuable product of alcohol is removed from the waste water. There is typically no recycle step unless the water is recycled to the reactor feed prep and reactor sections.
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Alcohols

Beer, Booze, and Biofuels
Chemical Engineering for Non-Majors

Ed Gatzke
Kelly Kopchak, Jacob Lambert, Kayla Revelle

What is alcohol?

- In science, an alcohol is a chain of molecules that contain an -OH
- Naming depends on number of carbons

Alcoholic Beverages

- Alcohol produced in beverages is ethanol
- Ethanol has many effects on the human body
  - Disrupts biochemical reactions in the brain
  - Sleep and long term memory can be effected

History

- Alcohol has been a large part of human history
- Different regions developed different types
- All alcohol is created by fermentation
  - Processes differ greatly after fermentation
History in the United States

• 18th Amendment
  • Passed in 1920, prohibited the product, consumption, and sale of alcohol

• 21st Amendment
  • Repealed the 18th Amendment and prohibition in 1933

Moonshine History

• Moonshine
  • High-proof distilled spirits that are usually produced illegally

  • Originating in the Appalachian area
    • Moonshine was more profitable to transport than corn
    • Dangerous roads led to the rise of production

Proof

• 50% Alcohol by Volume (ABV) is 100 proof
• Pure Grain Alcohol
  • Highest possible proof at 190
• 200 proof alcohol absorbs water from humid air
  • Making it impossible produce

Types of Alcohol

• Wine and Beer
  • These types are fermented and then bottled or barreled

• Spirits
  • Undergoes fermentation but is then distilled
  • Distillation achieves a higher proof
Fermentation

- Fermentation process creates alcohol
- Wort
  - The liquid present before fermentation takes place
- Yeast consume sugars and create ethanol and CO₂
- Fermentation is also used in other food process
  - Bread production
  - Yogurt
  - Cheese

Beer

Beer, Booze, and Biofuels
Chemical Engineering for Non-Majors

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History of Beer

- Earliest known beer production was in Egypt
  - Beer dates back 2600 years
- It is the oldest known alcoholic drink
- Early beers did not contain hops which were later discovered to add taste

History of Beer

- Earliest food purity law still in use has to do with beer
  - Reinheitsgebot was adopted in 1516
- Only allowed three ingredients
  - Water
  - Hops
  - Barley-malt
- Today brewing is a global industry
Background

- Beer is produced by the fermentation of malts
  - Malt is a germinated cereal grain that has undergone malting
- Six steps required to make most beers
  - Malting
  - Kilning
  - Milling
  - Mashing
  - Fermenting
  - Bottling

Malting

- To begin the process the malts must be harvested
  - Malting is done to isolate enzymes needed for brewing
  - Harvested malts are immersed in water to encourage sprouting
  - They are then dried as sprouting begins to halt the process

Kilning

- The final stage of traditional malting
  - Kilning is done to decrease the malt’s moisture content
  - After the malts are dried the milling process can begin

Milling

- The outer layer, the husk, is removed
  - This is done by crushing the malts
- The inner layer, the endosperm, is removed next
  - This allows the maximum enzyme harvest
  - Milling is important for a successful mashing step
Mashing

• The malt is placed in hot water
  • The water should not be too hot to the point of boiling
  • This step extracts the enzymes and sugars from the malts
  • These components are vital to the brewing process

Fermenting

• To begin this step, water and malt sugars are combined
  • This mixture, the wort, is then boiled
• After boiling, hops are added to the wort
  • The hops help to add flavor
  • The wort is then placed in vessels and yeast is added
  • This is done at different temperatures depending on the beer
  • Fermentation can last anywhere from weeks to months

Bottling

• Bottling is the final step in the process
  • The beer has been fully fermented
  • Bottling is done differently at each brewery
    • It is typically an automated process filling bottles or cans

Differences in Beer

• Specific ingredients and types of hops are very important
• Fermentation length and temperature have a great effect
• Beers fall into two main categories
  • Lagers
  • Ales
Lagers vs Ales

- Different type of yeast used
- Yeast ferment at either the top or the bottom of the barrel
  - Lagers
    - Bottom fermenting yeast at 25-50°F
  - Ales
    - Top fermenting yeast at 60-75°F

What is the most popular beer in the U.S.?

A Coors Light
B Bud Light
C Budweiser
D Corona Light
E Pabst Blue Ribbon

B Bud Light

Different Types

- Pale Ale
  - Brewed with "pale" malts that were lightly roasted
  - Gives less of a burnt or cooked and full flavor
- Wheat Beer
  - Ale brewed with larger wheat to barley ratio
  - Produces ester and other by-products
  - Has a sweet and slightly tangy taste

Different Types

- Indian Pale Ale (IPA)
  - Hoppy brew born out of English pale ales
  - Extra hops were added to preserve the brew while being transported
  - Necessary to transport from England to India
- Amber Ale
  - Brewed with amber or crystal malts
  - Are typically darker in color with more of a caramel flavor
Different Types

- Porter
  - A dark ale consisting of hops and brown malts
  - Has a very dark color compared to other ales
  - Differ from stouts by not having a roasted barley flavor
- Cider
  - More similar to champagne than other beer types
  - Fermented from pressed apples and a longer strand of yeast

Beer, Booze, and Biofuels

Wine

*Wine is sunlight, held together by water*

-Galileo Galilei

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Where is the “birthplace of wine”

A France
B Spain
C Italy
D Caucasus Mountain Region
E China
D Caucasus Mountain Region and more specifically the country of Armenia

What is wine?

- Wine is an alcoholic beverage made from fermented grapes
- The grapes are fermented without any additional nutrients being added such as sugar, acids, or enzymes
- The sugars within the grapes are consumed by yeast which then produces ethanol and carbon dioxide
- Depending upon the type of grapes and strain of yeast, the style of the wine will vary
Winemaking

https://www.youtube.com/watch?v=YoPZmHOT7dg

Red wine vs White wine

During the fermentation process, red wine is given its darker color from leaving pieces of the grapes and stems in the juice and later filtering it out.

White wine is different with only the juice being fermented keeping its color lighter.

Wine Types

Chardonnay
- A green-skinned grape used to produce white wine
- Originated in eastern France but is now grown all over the world
- Described as having flavors of plum, apple, and pear

Pinot Grigio
- A grayish-blue grape used to produce white wine
- Grown all over the world
- Full-bodied wine with notes of melon and mango

Merlot
- A dark blue grape used to produce red wine
- Widely planted in the Bordeaux regions
- Will either taste of plum and blackberry or raspberries and strawberries depending on the harvesting time

Pinot Noir
- A “black” grape used to produce red wine
- Typically associated with France but is grown in cooler regions
- Tastes of cherries, raspberries, and strawberries
Wine Types

Moscato (Muscat)
- A family of grapes with colors ranging from white to yellow to black
- Grown in Italy, Australia, and Spain
- Creates a very grapey aroma with notes of citrus and peach

Cabernet Sauvignon
- A “black” grape used to produce red wine
- Grown in all major wine producing countries
- Depending on climate, notes range from mint and cedar to black cherry and black olive

Sake
- “You mean that rice wine?” - Blake Shelton
- Japanese rice wine made from fermented rice
- More similar process to beer than wine
- The bran has to be removed from the rice before the brewing process
- National beverage of Japan

Champagne
- Sparkling white wine made with grapes from the Champagne region of France
- While bottled, undergoes secondary fermentation to add carbonation

Inside the bottle
Yeast + Sugar → Ethanol + Carbon Dioxide

Spirits

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Background

- Sprits made very similarly to wine and beer
  - Undergoes fermentation process with yeast
- Different base ingredients undergo fermentation process
  - Fruits
  - Sugars
  - Plants

Process

- Base ingredient is mashed and milled
  - Releases sugars and enzymes into wort
- Type of ingredient determines final product
  - Whiskey
  - Vodka
  - Tequila
  - Rum

- Alcohol-Water mixture is then distilled
  - Involves column and still apparatus
  - Ethanol boils at lower temperature than water
  - Ethanol leaves as a vapor
    - Separates alcohol from water and other waste materials

- Foreshot
  - The first liquid to leave the batch still
  - Contains low-boiling light components such as methanol

- Thumper
  - A liquid filled tank that bubbles vapors through
  - Results in a higher proof alcohol
Process

- Ethanol vapor is then condensed
  - Occurs by running cooling water outside the tubes
- Condensate is then collected
  - Can be distilled again or used as finished product

What is the most popular liquor in the U.S.?

A. Jack Daniels Tennessee Whiskey
B. Crown Royal Whisky
C. Bacardi Rum
D. Smirnoff Vodka
E. Never heard of these

D. Smirnoff Vodka

Different Types

- Brandy
  - Made from the distillation of wine
  - Typically 70-120 proof
  - Sweeter tastes of dried fruit and citrus zest
- Rum
  - Made from fermented sugar cane juice
  - Can range from 90-120 proof
  - Contains notes of molasses and syrup

Different Types

- Whiskey
  - Distilled from fermented grain mash
  - Aged in oak barrels after distillation
  - Wide range of different types of whiskey
- Tequila
  - Produced from fermentation and distillation of agave plant
  - Specialty yeast is usually required for fermentation
  - Must be made at 80 proof in United States
Different Types

- **Gin**
  - Neutral grain spirit is re-distilled with botanicals
  - Produced from fermentation of the juniper plant
  - Must be at least 80 proof in United States

- **Vodka**
  - Produced from grains and typically of Russian origin
  - Distilled multiple times through activated charcoal
  - Consists of water and alcohol with minimal impurities

Types of Whiskey

- **Bourbon**
  - Must be made in the United States
  - Must be at least 51% corn and distilled at 160 proof or less
  - Must be barreled at 125 proof or less and aged in new oak charred barrels

- **Rye Whiskey**
  - Required to contain 51% rye grass
  - Has to be aged in new, charred, American oak barrels

- **Tennessee Whiskey**
  - Produced in Tennessee similarly to bourbon
  - Before barreling, whiskey is charcoal filtered
  - Must be barreled and aged in new oak charred barrels

- **Irish Whiskey**
  - Must be distilled in Ireland
  - Required to age a minimum of three years in oak barrels

- **Scotch**
  - Whiskey that is distilled in Scotland
  - Primarily made from malted barley
  - Must be barreled and aged in new oak barrels for three years

- **Canadian Whisky**
  - Must be distilled and aged in Canada
  - Typically made from rye and some other grains are used
  - Used Canada often referred to as just rye whisky
Unit Operations and Conversions
A Milli- A Milli- A Milli-
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Who is this?
A Isaac Newton (1642-1726)
B Joseph Gay-Lussac (1778-1850)
C Amedeo Avogadro (1776-1856)
D Lord Kelvin (1824-1907)
E I have no clue and don't care

D Lord Kelvin (1824-1907)
He is known for determining the correct value of absolute zero

Why Do We Need Units?
• The mass of this object is 2
  • 2 what?????
• Units give values relative to other objects in our universe

Definitions
• Base Unit- base quantity used as the standard for a specific measurement and cannot be broken down into further units
  • Mass: matter in an object
  • Length: distance from end to end of an object
  • Time: the period between two events
  • Temperature: how hot or cold an object is
• Systems of Measurement:
  • International System (SI) or Metric
  • English
**SI Units**

<table>
<thead>
<tr>
<th>Base Quantity</th>
<th>Common Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>meter (m)</td>
</tr>
<tr>
<td>Mass</td>
<td>kilogram (kg)</td>
</tr>
<tr>
<td>Time</td>
<td>second (s)</td>
</tr>
<tr>
<td>Temperature</td>
<td>Celsius (°C)</td>
</tr>
</tbody>
</table>

**SI Prefixes**

- The SI system is based on units of 10
- You can change units by using the conversion factors

**Examples:**
- \( 5 \text{ m} \times \frac{1 \text{ cm}}{10^{-2} \text{ m}} = 500 \text{ cm} \)
- \( 0.0032 \text{ kg} \times \frac{10^3 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ mg}}{10^{-2} \text{ g}} = 3200 \text{ mg} \)

**English Units**

<table>
<thead>
<tr>
<th>Base Quantity</th>
<th>Common Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>foot (ft)</td>
</tr>
<tr>
<td>Mass</td>
<td>pound (lb)</td>
</tr>
<tr>
<td>Time</td>
<td>second (s)</td>
</tr>
<tr>
<td>Temperature</td>
<td>Fahrenheit (°F)</td>
</tr>
</tbody>
</table>

**English Unit Conversion**

<table>
<thead>
<tr>
<th>Length</th>
<th>Mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 inches (in)  = 1 foot (ft)</td>
<td>16 ounces (oz) = 1 pound (lb)</td>
</tr>
<tr>
<td>3 ft = 1 yard (yd)</td>
<td>2000 lb = 1 ton</td>
</tr>
<tr>
<td>5280 ft = 1 mile (mi)</td>
<td></td>
</tr>
</tbody>
</table>

**Example:**
- \( 1542 \text{ ft} \times \frac{1 \text{ mi}}{5280 \text{ ft}} = 0.2920 \text{ mi} \)
Time Conversions

- SI and English systems use the same units and conversions for time:
  - 60 seconds (s) = 1 minute (min)
  - 60 min = 1 hour (hr)
  - 24 hr = 1 day
  - 7 days = 1 week (wk)
  - 365 days = 1 year (yr)
  - 52 wks = 1 yr

**Example:**

\[
2 \text{ yrs} \times \frac{365 \text{ days}}{1 \text{ yr}} \times \frac{24 \text{ hr}}{1 \text{ day}} \times \frac{60 \text{ min}}{1 \text{ hr}} = 1,051,200 \text{ min}
\]

Converting Between SI and English Units

<table>
<thead>
<tr>
<th>SI Unit</th>
<th>English Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.54 cm</td>
<td>1 in</td>
</tr>
<tr>
<td>1 m</td>
<td>3.2808 ft</td>
</tr>
<tr>
<td>454 g</td>
<td>1 lb</td>
</tr>
</tbody>
</table>

**Examples:**

\[
57 \text{ in} \times \frac{2.54 \text{ cm}}{1 \text{ in}} = 145 \text{ cm}
\]

\[
3928 \text{ g} \times \frac{1 \text{ lb}}{454 \text{ g}} \approx 8.652 \text{ lb}
\]

Absolute Temperature

- Celsius and Fahrenheit are the most common temperature scales used on a daily basis
- Kelvin and Rankine are absolute temperature scales meaning that the coldest physical temperature occurs at zero

<table>
<thead>
<tr>
<th>Scale</th>
<th>Boiling Point</th>
<th>Freezing Point</th>
<th>Absolute Zero</th>
</tr>
</thead>
<tbody>
<tr>
<td>Celsius</td>
<td>100</td>
<td>0</td>
<td>-273</td>
</tr>
<tr>
<td>Fahrenheit</td>
<td>212</td>
<td>32</td>
<td>-460</td>
</tr>
<tr>
<td>Kelvin</td>
<td>373</td>
<td>273</td>
<td>0</td>
</tr>
<tr>
<td>Rankine</td>
<td>672</td>
<td>492</td>
<td>0</td>
</tr>
</tbody>
</table>

Temperature Conversions

- **Celsius (°C) to Fahrenheit (°F)**
  \[\text{°F} = \left(\frac{9}{5}\times \text{°C}\right) + 32\]
- **Fahrenheit (°F) to Celsius (°C)**
  \[\text{°C} = \left(\frac{5}{9}\times (\text{°F} - 32)\right)\]
- **Celsius (°C) to Kelvin (K)**
  \[K = \text{°C} + 273\]
- **Fahrenheit (°F) to Rankine (R)**
  \[R = \text{°F} + 460\]
Temperature Examples

Fahrenheit to Celsius:
\[ \frac{5}{9} \times (75 \, ^\circ F - 32) \approx 24 \, ^\circ C \]

Celsius to Kelvin:
24 \, ^\circ C + 273 = 297 \, K

Kelvin to Rankine:
\[ \frac{5}{9} \times 277 \, ^\circ C + 32 = 530.6 \, ^\circ F \]
\[ 530.6 \, ^\circ F + 460 \, R = 990.6 \, R \]

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Temperature Measuring Device

**Thermocouple**: uses two wires with different charges to measure the current flowing between the wires which correlates to the temperature.

➤ This is what you will use in the lab to measure temperature.

Area

• Definition: the amount of space enclosed within a boundary

• Units: m², ft²

<table>
<thead>
<tr>
<th>Shape</th>
<th>Equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangle</td>
<td>( A = lw )</td>
</tr>
<tr>
<td>Circle</td>
<td>( A = \pi r^2 )</td>
</tr>
<tr>
<td>Triangle</td>
<td>( A = \frac{bh}{2} )</td>
</tr>
</tbody>
</table>

Area Example

What is the area of this circle in yd²?

\[
A = \pi r^2 = \frac{\pi (2.5 \, m)^2}{(5 \, ft)^2} = 19.63 \, m^2
\]

\[
19.63 \, m^2 \times \left(\frac{3.2808 \, ft}{1 \, m}\right)^2 \times \left(\frac{1 \, yd}{3 \, ft}\right)^2 = 23.48 \, yd^2
\]
More Conversions and Calculations

Under Pressure

Beer, Booze, and Biofuels
Chemical Engineering for Non-Majors

Ed Gatzke
Kelly Kopchak, Jacob Lambert, Kayla Revelle

Who is this?

A Blaise Pascal (1623-1662)
B Albert Einstein (1879-1955)
C Isaac Newton (1643-1727)
D Archimedes (287 BCE-212 BCE)
E Evangelista Torricelli (1608-1647)

C Blaise Pascal (1623-1662)
He made major contributions to science and was honored with the SI unit of pressure, Pascal (Pa).

Definitions

- **Pressure**: the continuous physical force exerted on or against an object by something in contact with it
  - This contact does not have to be direct
  - Force per unit area
- **Volume**: the amount of space that an object or substance occupies in three dimensional space
- **Density**: the measure of the compactness of an object or substance
  - Mass of a substance per unit volume
- **Specific Gravity**: the density of a substance in question to the density of a specific standard (typically water)

Pressure Equation

\[ P = \frac{F}{A} \]

- \( P \) = Pressure [Pascal (Pa) or N/m²]
- \( F \) = Force [Newton (N) or \( \text{kg} \cdot \text{m} / \text{s}^2 \)]
- \( A \) = Area (m²)
Pressure Units and Conversions

<table>
<thead>
<tr>
<th>Measurement System</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>SI</td>
<td>Pascal (Pa)</td>
</tr>
<tr>
<td>English</td>
<td>pound-force per square inch (psi)</td>
</tr>
</tbody>
</table>

Pressure Conversions

- 101,325 Pa = 14.7 psi
- 1 atm = 14.7 psi
- 1 psi = 760 mm Hg
- 1 bar = 100 kPa
- 1 atm = 101,325 Pa

Weight vs. Mass

- **Weight**: the force of gravity working upon an object
  - Dependent on gravitational force
  - The weight of an object on Earth is different than the weight of an object on Jupiter
  - Units (same as force): N or $\text{kgm/s}^2$

- **Mass**: measurement of matter in an object
  - All objects have mass and the measurement does not change based on location (i.e. same on Earth and Jupiter)
  - Units: g or lb

Pressure Example

The weight (force) of the cube is 100 N. The length of the cube is 4 m. The width of the cube is 2 m. The height of the cube is 3.5 m. Calculate the pressure that the cube is exerting with respect to the table in psi.

Pressure Example con’t.

Which two sides of the cube should you use to calculate the area?

**Answer**: The length and the width because those are the two sides in contact with the table.
Pressure Example con’t.

\[ P = \frac{F}{A} \]

\[ A = l \times w = 4 \text{ m} \times 2 \text{ m} = 8 \text{ m}^2 \]

\[ P = \frac{100 \text{ N}}{8 \text{ m}^2} = 12.5 \frac{\text{N}}{\text{m}^2} = 12.5 \text{ Pa} \]

\[ P = 12.5 \text{ Pa} \times \frac{14.7 \text{ psi}}{101,325 \text{ Pa}} = 0.00181 \text{ psi} \]

Atmospheric vs. Gauge Pressure

**Atmospheric Pressure**: the pressure at sea level exerted by the weight of the atmosphere

- \[ P_{\text{atm}} = 101,325 \text{ Pa} = 101.3 \text{ kPa} = 14.7 \text{ psi} \]
- As height above sea level increases, atmospheric pressure decreases. For all standard calculations, \( P_{\text{atm}} \) is the pressure at sea level.

**Gauge Pressure** \( P_g \): a device used in chemical processes and in chemistry to measure pressure.

- It gives a pressure reading that incorporates the atmospheric pressure as part of its calibration.

Calculating Gauge Pressure

- **Absolute Pressure**: the zero referenced against a perfect vacuum
- You will want to use \( P_{\text{abs}} \) in your calculations unless told otherwise

\[ P_{\text{abs}} = P_g + P_{\text{atm}} \]

Volume

- **Cube**: \( V = l \times w \times h \)
- **Sphere**: \( V = \frac{4}{3} \pi d^3 \)
- **Cylinder**: \( V = \pi d^2 \frac{h}{4} \)
### Volume Conversions

#### Volume Units

<table>
<thead>
<tr>
<th>Conversion</th>
<th>Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 cups (c)</td>
<td>1 pt (pt)</td>
</tr>
<tr>
<td>1 pt (pt)</td>
<td>1 L (L)</td>
</tr>
<tr>
<td>1 L (L)</td>
<td>1,000 cm³</td>
</tr>
<tr>
<td>32 ounces (oz)</td>
<td>1 qt (qt)</td>
</tr>
<tr>
<td>1 qt (qt)</td>
<td>1 gal (gal)</td>
</tr>
<tr>
<td>1 gal (gal)</td>
<td>3.78 L</td>
</tr>
<tr>
<td>1 ft (ft)</td>
<td>12 in (in)</td>
</tr>
<tr>
<td>1 in (in)</td>
<td>2.54 cm</td>
</tr>
<tr>
<td>1 cm (cm)</td>
<td>0.394 ft</td>
</tr>
</tbody>
</table>

### Volume Example

If a cylinder with a diameter of 4 feet and a height of 10 feet is placed inside a cube with dimensions of 11 feet in length, 15 feet in width, and 17 feet in height, what is the remaining volume within the cube in gallons?

#### Volume Example con’t.

**Cube:**

\[ V = 11 \text{ ft} \times 15 \text{ ft} \times 17 \text{ ft} = 2,805 \text{ ft}^3 \]

**Cylinder:**

\[ V = \frac{\pi \times (4 \text{ ft})^2 \times 10 \text{ ft}}{6} = 125.66 \text{ ft}^3 \]

**Leftover Volume:**

\[ V = 2,805 \text{ ft}^3 - 125.66 \text{ ft}^3 = 2,679.34 \text{ ft}^3 \]

\[ V = 2,679.34 \text{ ft}^3 \times \frac{1 \text{ gal}}{0.134 \text{ ft}^3} = 19,995 \text{ gal} \]

### Density

\[ \rho = \frac{m}{V} \]

- \( \rho \) = Density [kg/m³ or lb/ft³]
- \( m \) = Mass [kg or lb]
- \( V \) = Volume [m³ or ft³]

1 kg/m³ = 0.0642 lb/ft³
Density Measuring Device

Densitometer: measures the degree of darkness of a material
- Directly correlates to the density of the material via calibration and can be used in mathematical equations

Specific Gravity

\[ SG = \frac{\rho_{\text{object}}}{\rho_{\text{H}_2\text{O}}} \]

- SG = Specific Gravity [unitless]
- \( \rho_{\text{object}} \) = density of the object [kg/m\(^3\) or lb/ft\(^3\)]
- \( \rho_{\text{H}_2\text{O}} \) = density of water [kg/m\(^3\) or lb/ft\(^3\)]
- \( \rho_{\text{H}_2\text{O}} = 1 \text{ kg/m}^3 = 0.0642 \text{ lb/ft}^3 \)

Density and Specific Gravity Example

The mass of the Sun is 1.989 x 10\(^{30}\) kg. The radius of the Sun is 6.96 x 10\(^8\) m.

a) Calculate the density of the Sun.

b) Calculate the specific gravity of the Sun with respect to water.

Density and Specific Gravity Example con’t.

\[ V = \frac{\pi d^3}{6} \]
\[ d = 2r = 2 \times (6.96 \times 10^8 \text{ m}) = 13.92 \times 10^8 \text{ m} \]
\[ V = \frac{\pi (13.92 \times 10^8 \text{ m})^3}{6} = 1.41 \times 10^{27} \text{ m}^3 \]
\[ \rho = \frac{1.989 \times 10^{30} \text{ kg}}{1.41 \times 10^{27} \text{ m}^3} \approx 1410 \text{ kg/m}^3 \]
\[ SG = \frac{1410 \text{ kg/m}^3}{1 \text{ kg/m}^3} = 1410 \]
Another important base unit is the amount of a material.

**Unit:** moles \([\text{mol}]\)

1 mol = \(6.02 \times 10^{23}\) molecules/particles/atoms \(\rightarrow\) Avagadro's Number

**Purpose:** in chemistry, it is used to describe the amount of atoms or molecules reacting together and what product they produce.

This concept will be discussed further once we start general chemistry.

---

**Extensive vs. Intensive Properties**

- **Extensive properties:** depend on size of the material or object
  - Examples include volume, mass, surface area, amount of substance

- **Intensive (bulk) properties:** independent of size and are physical properties of the material or object under specific conditions
  - Examples include density, specific gravity, pressure, boiling point, melting point, concentration, and temperature
Significant Figures

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Who is this?
A Sheldon Cooper
B Dwight Schrute
C Howard Wolowitz
D Ron Swanson
E Penny

C Howard Wolowitz
Played by Simon Helberg in The Big Bang Theory
here to remind you to mind your significant figures.

What are Significant Figures?
- Significant figures are the number of digits that have numerical value
- They are used to express the degree of accuracy of a number
- The number of significant digits increases as the accuracy increases

Significant Figure Rules
1. All digits 1-9 are significant
2. Zeros within a number are significant
   - 9.302 has 4 significant figures
3. Zeros establishing the location of the decimal point are not significant
   - 32,000 has 2 significant digits
4. Trailing zeros after the decimal point, not setting the place, are significant.
   - 5.00 has 3 significant figures.
Significant Figures in Mathematical Operations

**Rule of thumb:** the final answer cannot have more significant figures than the number of least significant figures in the original measurements.

Significant Figures in Addition and Subtraction

- **Rule:** the answer cannot contain more decimals than the least accurate measurement.
  - **Example:** $167.0 + 0.9842 = 168.0$
  - The first number has 4 significant digits and the second has 5, therefore the final solution cannot have more than 4 significant digits.

Significant Figures in Multiplication and Division

- The solution cannot have more significant figures than the least accurate measurement.
- The number of significant digits is counted instead of decimal places.
  - **Example:** $42.50 \times 0.500 = 21.3$
  - There are 4 significant digits in the first number and 3 in the second, therefore, the final solution cannot have more than 3 significant digits.

Rounding Rules

1. If the answer ends in a 0, 1, 2, 3, or 4, the solution is rounded down to the preceding digit by dropping the final estimated digit.
   - **Example:** $21.34 = 21.3$
2. If the answer ends in 5, 6, 7, 8, or 9, the solution is rounded up by adding 1 to the preceding digit.
   - **Example:** $21.35 = 21.4$
**Scientific Notation**

Scientific notation makes very large or very small numbers easier to work with:

- $700 = 7 \times 10^2$ (1 significant figure)
- $0.0000000032 = 3.2 \times 10^{-10}$ (2 significant figures)
- $6,000,740,000 = 6.00074 \times 10^9$ (6 significant figures)
Biofuel Basics
Beer, Booze, and Biofuels
Chemical Engineering for Non-Majors

Ed Gatzke
Kelly Kopchak, Jacob Lambert, Kayla Revelle

Compressed Natural Gas (CNG)

- Methane stored at high pressure
- Alternative fuel source to gasoline and Diesel fuel
- Releases fewer undesirable gases
- Safer than other fuels during a spill
- Lighter than air so disperses quickly

How it’s made

- Made by compressing natural gas
- Compressed to less than 1% of standard volume
- Usually stored in cylindrical or spherical tanks
- Can be used in internal combustion engines
- Must be modified from traditional engines

Dedicated vs Dual Fuel

- Dedicated engines
  - Use only compressed natural gas
- Dual Fuel
  - Contain compressed natural gas and gasoline systems
  - Gasoline system is used to extend driving range
Where in the world?
• CNG engines are growing in popularity
  • Iran
  • Pakistan
  • Indian capital city of Delhi
• Growing in popularity due to increasing gas prices

Why isn’t this being used?
• Cost and placement of fuel storage tanks
  • Early adopters are public transportation
  • Cost of fuel tanks has decreased as more are implemented
• Number of vehicles has grown
  • Steady 30% increase every year

Advantages
• Lower maintenance costs than traditional vehicles
• No loss or evaporation of fuel
  • CNG fuel systems are completely sealed
• Less pollution
  • Emits significantly less greenhouse gases

Disadvantages
• Storage tanks require more space than traditional fuels
• CNG designed cars accommodate larger tanks
  • Tanks are installed under the body of the vehicle
  • Tanks can compromise structural integrity of vehicle
E85

- E85 is an ethanol gasoline fuel blend
  - Refers to a mixture that is 85% ethanol fuel by volume
- In the United States
  - Percentages can vary from 51-83%
- Elsewhere in the world
  - E85 is 85% ethanol

Why not always 85%?

- Ethanol has a lower heating value than gasoline
  - More difficult to crank engines in cold temperatures
  - Mixing varying fractions help combat this problem
- Many other countries that use E85 have warm climates
  - Brazil
  - Australia

Flex Fuel Vehicles

- Vehicles designed to run on multiple fuels
  - Typically gasoline and ethanol or methanol
  - Both fuels are stored in same tank
- Many different car makers have developed flex fuel vehicles
  - Original Ford Model T ran on either gasoline or ethanol
  - Ford- Taurus
  - Dodge- Caravan
Chemistry Basics

Beer, Booze, and Biofuels
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Who is this?
A. John Dalton (1766-1844)
B. Dmitri Mendeleev (1834-1907)
C. Linus Pauling (1901-1994)
D. Antoine-Laurent de Lavoisier (1743-1794)
E. I have no clue and don’t care

D Antoine-Laurent de Lavoisier
He was a French noble man who is widely considered the “father of modern chemistry”

Scientific Method
1. Propose a question
2. Systematic observation
3. Form a hypothesis
4. Test your hypothesis
5. Analyze your data
6. Communicate your results

Definitions
- Chemistry: the study of substances, their identification, properties, how they interact, react and change
- Scientific method: the process used in experimentation to explore observations and answer questions about the natural world
- Atom: the building blocks of matter
- Element: basic form of all matter; consists of a single type of atom
- Periodic Table: common chart of all known elements
1. Propose a Question

- What would you like to learn?
  - Who?
  - What?
  - When?
  - Where?
  - Why?
  - How?

2. Systematic Observation

- Background research can be conducted many ways:
  - Textbooks
  - Scholar papers
  - Encyclopedias
  - Online

3. Form a Hypothesis

- **Hypothesis**: educated guess based on observations
  - Testable by experimentation
  - Able to be measured
  - Must be able to be proved wrong

4. Test Your Hypothesis

- Use a variety of laboratory experiments
- Experiment must be able to be repeated
- Fair and unbiased test
- Tests include independent and dependent variables
5. Analyze Your Data

- Use the data collected during experimentation to analyze it using calculations and graphs
- Determine if the experiment supports your hypothesis
- If your results do not match your hypothesis, you still report them
- Restart the process with a new hypothesis

6. Communicate Your Results

- Share all findings and conclusions
  - Report
  - Lab report
  - Journals
  - Conferences

Chemistry Building Blocks

- **Atoms**: smallest particles of matter which make up everything
- **Elements**: made up of one type of atom
- **Molecules**: combination of atoms
- **Compounds**: different types of atoms

Parts of an Atom

- **Nucleus**: center of the atom containing protons and neutrons
- **Proton**: positively charged particles
- **Neutron**: neutral particles
- **Electron**: negatively charged particles orbiting around nucleus
Periodic Table

- Consists of all known elements in the universe
- Arranged based on increasing atomic number
  - Atomic number: number of protons in the nucleus
  - Atomic mass: average of protons and neutrons in the nucleus

Molecules and Compounds

- **Molecule**: the smallest unit of a chemical
  - Can be composed of the same or different atoms
- **Compound**: a molecule consisting of different elements
  - 1 mole of substance = 6.022 \times 10^{23} molecules (known as Avagadro’s Number)
Chemical Equations

Beer, Booze, and Biofuels
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Who is this?

A Isaac Newton (1642-1726)
B Joseph Gay-Lussac (1778-1850)
C Amedo Avogadro (1776-1856)
D Friedrich Wilhelm Heinrich Alexander von Humboldt (1769-1859)
E I have no clue and don’t care

C Amedo Avogadro (1776-1856)
Avogadro’s constant for 1 mole of molecules

Definitions

- **Reactants**: starting materials of a reaction
- **Products**: created as a result of a reaction
- **Stoichiometry**: quantitative relationship between products and reactants
- **Organic compound**: compounds associated with life processes containing carbon atoms

What is a Mole?

- Amount of a substance present
  1 mole = $6.022 \times 10^{23}$ molecules
- Used for stoichiometric quantities
Stoichiometry

- Stoichiometry: used to balance chemical equations
- A balanced stoichiometric equation allows you to determine the amount of products that can be formed from a given amount of reactants
- The ratio **coefficient** tells you how many moles are present of a given substance

Balancing Chemical Equations

A balanced chemical equation means that the number of atoms on the reactants side equals the number of atoms on the products side

Reactants $\rightarrow$ Products

**Beer, Booze, and Biofuels**

Balancing Chemical Equations

A balanced chemical equation means that the number of atoms on the reactants side equals the number of atoms on the products side

**Stoichiometry Example**

NaCl and MgF$_2$ react to form the products NaF and MgCl$_2$. Use stoichiometry to balance this equation.

\[
\begin{align*}
2 \text{NaCl} + 1 \text{MgF}_2 & \rightarrow 2 \text{NaF} + 1 \text{MgCl}_2 \\
\text{2 NaCl} + 1 \text{MgF}_2 & \rightarrow 2 \text{NaF} + 1 \text{MgCl}_2
\end{align*}
\]

**Stoichiometric Example con’t.**

What is the stoichiometric ratio of NaCl to MgF$_2$, NaF, and MgCl$_2$?

- NaCl to MgF$_2$ $\rightarrow$ 2:1
- NaCl to NaF $\rightarrow$ 2:2 or 1:1
- NaCl to MgCl$_2$ $\rightarrow$ 2:1
Molecular Weight Calculation

**Step 1:** Identify the molecular weight of each element using the periodic table

**Step 2:** Multiply the molecular weight by the number of individual atoms in the molecule

**Step 3:** Add all of the molecular weights in one molecule together

---

Molecular Weight Example

Calculate the molecular weight of $K_2S$.

Molecular Weight of $K$: 39.10 g/mol  
Molecular Weight of $S$: 32.06 g/mol

$$\text{MW}_{K_2S} = 2(39.10) + 1(32.06) = 110.26 \text{ g/mol}$$

---

Calculating Moles from Molecular Weight

Given the mass of a compound, you are able to calculate the moles of the molecule present:

**Step 1** – Calculate molecular weight

**Step 2** – Divide given mass (g) by molecular weight (g/mol) to calculate the moles in the molecule

---

Calculating Moles using Molecular Weight

How many moles are present in 100.0 g of $K_2S$?

From previous example: $\text{MW}_{K_2S} = 110.26 \text{ g/mol}$

$$\frac{100.0 \text{ g } K_2S}{110.26 \text{ g/mol } K_2S} = 0.9069 \text{ mol } K_2S$$
Calculating Mass using Molecular Weight

Given the moles of a compound, you are able to calculate the mass of the molecule present:

**Step 1** – Calculate molecular weight

**Step 2** – Multiply given moles (mol) by molecular weight (g/mol) to calculate the mass of a molecule

---

What is the mass of 2.00 mols of K₂S?

From previous example: MWₖ₂ₛ = 110.26 g/mol

\[ 2.00 \text{ mols} \times 110.26 \frac{g \text{ K}_2\text{S}}{\text{mol K}_2\text{S}} = 221 \text{ g K}_2\text{S} \]

---

Sugar

- Sugar is commonly used in alcohol making processes
- Organic compound
- Molecular Formula: C₆H₁₂O₆
- Molecular Weight: 180 g/mol

---

[Image of sugar]
More Chemistry Basics

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E I have no clue and don’t care

C Amedo Avogadro (1776-1856)
Avogadro’s constant for 1 mole of molecules

Definitions

- **Limiting reactant**: substance that is completely used in a chemical reaction
- **Activation energy**: amount of energy needed to start a chemical reaction
- **Catalyst**: substance that speeds up a chemical reaction
- **Equilibrium**: the point when the rate of the forward reaction equals the rate of the reverse reaction

Phases of Matter

- **Solid**: firm, rigid, set volume, cannot be compressed
- **Liquid**: fluid, finite volume, cannot be compressed
- **Gas**: fluid, no volume/shape, compressible
Phase Diagram

Limiting Reactant

**Limiting reactant:** the reactant that is completely used at the end of a chemical reaction

**Excess reactant:** the reactant that has not been completely used at the end of a chemical reaction

Limiting Reactant

4 pieces of toast + 3 pieces of cheese

Limiting: Toast
Excess: Cheese

Equilibrium

Before Equilibrium

More mols of A than B

Equilibrium Reached

Products are equal to reactants
**Activation Energy and Catalyst**

- **Activation energy**: amount of energy needed to start a chemical reaction
- **Catalyst requirements**:
  - Speeds up reaction
  - Cannot be consumed by reaction
  - Does not change the equilibrium of the reaction
  - Catalysts reduce activation energy needed to start reaction

**Chemical Processes**

**Aerobic**:
- Uses air as reactant or catalyst in the reaction
- Takes place in presence of oxygen

**Anaerobic**:
- Oxygen/air is not present
- Example: fermentation (used in making beer, wine, and spirits)

**Cellular respiration**:
- Occurs when a cell extracts sugar from a molecule using oxygen
Energy Accumulation = In – Out + Created – Destroyed

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Energy

- Energy cannot be created or destroyed
- First Law of Thermodynamics
- Total energy has remained constant throughout time
  - Convert and changed, but never created

Basic Mass Balance

\[ \text{Accumulation} = \sum \text{In} - \sum \text{Out} + \sum \text{Created} - \sum \text{Destroyed} \]

- Overall solution must equal zero!
- This equation can also relate to energy

Basic Energy Balance

\[ E = U + KE + PE \]

- \( E \) is energy
- \( U \) is internal energy
- \( KE \) is kinetic energy
- \( PE \) is potential energy
Kinetic Energy

- One type of energy is kinetic energy
- Energy due to motion
- Also known as mechanical energy

Potential Energy

- Other type of energy is potential
- Many different forms
- Gravitational
- Chemical
- Elastic (spring)
- Electrical

Potential Energy

Example of Gravitational Potential Energy

Potential energy of object 10 feet up in the air > Potential energy of object on ground

Potential Energy

- Chemical potential energy
  - Energy transferred during chemical reaction
- Elastic potential energy
  - Energy of spring due to positioning
- Electrical potential energy
  - Energy dependent on point charges in electric field
Kinetic vs Potential

Kinetic energy can be converted to potential energy and vice versa.

Ex. An object 10 ft off the ground could fall due to gravity. The ball loses its potential energy but gains kinetic energy as it is speeding towards the Earth.

Units of Energy

- SI unit for energy is a Joule
  - Defined as 1 kg/m²
  - English unit is a foot-pound (lbₜ)
- In Earth's 9.8 m²/s² gravity, a 102 g object 1 meter above sea level has 1 joule of energy

Work

- In chemical engineering, work is causing an object to move by force
  - Work can be positive or negative
  - Expansion work
    - Gas expands in a controlled environment
  - \( W = -P \cdot dV \)
  - \( E = W + q \)

Power

- Power is the rate of work being done
  - Energy consumed per time
- Units are Watts (W)
  - \( W = \text{joule/second} \) for SI units
  - \( W = \text{foot-pounds/seconds} \)
Energy Content

• Common energy sources
  • Do work on system by producing heat or motion
• 1 gallon of gasoline
  • $1.3 \times 10^8$ Joules
  • Equivalent to 1.5 gallons of ethanol
  • Equivalent to 1.54 gallons of liquefied natural gas (LNG)
  • Equivalent to 2 gallons of methanol
  • Equivalent to 1 kg of hydrogen

Emissions

Energy sources discussed release $CO_2$ when burned

Coal > Diesel > Gas > Propane > Natural Gas (methane)

This has led to a shift away from coal towards natural gas

Latent Heat

• Latent heat is energy transferred
  • Has to be during constant temperature process
  • Typically occurs in phase changes
• Heat of vaporization
  • Substance goes from liquid to gas
• Heat of sublimation
  • Substance goes from solid to gas
• Heat of fusion
  • Substance goes from solid to liquid

Latent Heat

• Latent heat types are used often
  • Recorded and tabulated for many different temperatures
  • Used to solve energy balances
• Internal energy changes when a substance undergoes a latent heat process
Ideal Gas Law

- Ideal gas law only applies for STP conditions
  - 1 atm and 273 K
  - Low densities and no intermolecular forces

\[ P \cdot V = n \cdot R \cdot T \]
- \( P \) is pressure
- \( V \) is volume
- \( n \) is number of moles
- \( R \) is ideal gas constant
- \( T \) is temperature
Basics of Chemical Engineering

Beer, Booze, and Biofuels
Chemical Engineering for Non-Majors

Ed Gatzke
Kelly Kopchak, Jacob Lambert, Kayla Revelle

Who is this?

A Lewis M Norton (1855-1893)
B William H Walker (1869-1934)
C Harry E Armstrong (1848-1937)
D George E Davis (1850-1906)
E I have no clue and don’t care

D George E Davis (1850-1906)
He is considered to be the founding father of chemical engineering

Definitions

- Closed system: no mass is transferred but energy transferred across system boundaries
- Open system: mass and energy are transferred across system boundaries
- Isolated system: no mass/energy transferred across system boundaries
  - Rigid system: does not store energy
  - Non-rigid system: stores energy

Vessel/Tank

- Stores gases/liquids
- No reactions take place
- Kept at certain temperature and pressure
Mixer
- Combines two or more process streams into one
- Streams going in should be at same temperature and pressure

Compressor
- Increases pressure of gas by decreasing volume
- Used for gases

Pump
- Used with liquids
- Increases pressure and fluid flow rate

Turbine
- Used with liquids
- Decreases pressure
- Captures energy from the fluid
**Reactor**

- Where chemical reactions take place
- Products produced from reactants

**Types of Reactors:**
- **Batch:** closed system
- **Continuous:** open system, steady state, accumulation term is zero
- **Semi-Batch:** open system, mass transfer into vessel but doesn't exit system

![Batch Continuous Semi-Batch Reactors Diagram](https://upload.wikimedia.org/wikipedia/commons/thumb/1/15/Batch_reactor_STR.svg/80px-Batch_reactor_STR.svg.png)

**Separator**

- Separates wanted products from unwanted mixtures
- **Examples:**
  - Distillation column
  - Absorbers
  - Scrubbers
  - Membranes

![Separator Diagram](https://s-media-cache-ak0.pinimg.com/736x/94/1e/22/941e224b4e0dce01aaf1569faa9c5e65.jpg)

**Recycle Stream**

- After the separator, unused reactants are fed back into the process using a recycle stream
- Helps cut costs and keep stoichiometric ratios to the reactor constant

![Recycle Stream Diagram](https://s-media-cache-ak0.pinimg.com/736x/94/1e/22/941e224b4e0dce01aaf1569faa9c5e65.jpg)

**Still**

- Used to distill liquid mixtures by boiling the more volatile component
- It then cools the gas back to the pure liquid state
- Used in production of alcohol at small scale distilleries and moonshine making

![Still Diagram](https://s-media-cache-ak0.pinimg.com/736x/94/1e/22/941e224b4e0dce01aaf1569faa9c5e65.jpg)
Plate and Frame Filtration

- Separation apparatus for solid-liquid systems
- A slurry is pumped through filters and the solids collect on the filter while the liquid is pumped through
- Used in the production of beer

Engineering Design Process

1. Define problem
2. Do research
3. Specify requirements
4. Develop solutions
5. Choose best solution
6. Build prototype
7. Test
8. Redesign
Solving Chemical Engineering Problems

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Steps for Solving Chemical Engineering Problems

1. Read the problem
2. Write down the given measurements and make sure the units are consistent
3. Draw a block diagram
4. Identify what needs to be solved
5. Perform a degree of freedom analysis
6. Solve the problem using a balance for each substance and a total balance around each unit process
7. Check the answer

Drawing a Block Diagram

Write down what you know and what you are looking for

Knowns
Drawing a Block Diagram

Label your unknowns using any variables

Degree of Freedom (DoF) Analysis
• In order to solve a problem, it is important to know if it is in fact solvable
• DoF Analysis:
  • How many equations do I need?
  • Where do they come from?

\[ \text{DoF} = \#\text{ unknowns} - \#\text{ knowns} \]

Degree of Freedom Analysis
• If DoF is equal to zero, problem is solvable
• If DoF is greater than zero, problem is underspecified and needs more information
• If DoF is less than zero, problem is over specified and you need to decide what information is critical

Material Balances
Accumulation = In – Out + Generation
**Solving a Material Balance**

**How much water is leaving the mixer?**

**Mixer**

- In: 50 kg/s water, 50 kg/s water
- Out: x kg/s water

**Acc = In – Out + Gen**

0 = (50 + 50) – x + 0

x = 100 kg/s water

---

**Excess Feed**

- **Excess feed** – more reactant is fed than its stoichiometric ratio
- **Reasons for excess feed:**
  - Increase equilibrium
  - Increase selectivity (more of the wanted product)
  - Increase conversion

---

**Flows**

- **Flow rate**: flow of volume over a certain area over time
  - Units: volume/time
- **Mass flow rate**: mass of a fluid moving over a certain area over time
  - Units: mass/time
- **Molar flow rate**: moles of a fluid that move over a certain area over time
  - Units: moles/time
- **Velocity**: speed of a fluid in a given direction
  - Units: distance/time

---

**Fractions**

- **Used to describe amount of material or matter of each substance in a chemical compound**
- **Mole fraction** = moles of a specific substance / total moles of solution/mixture
- **Mass fraction** = mass of one substance / mass of total solution/compound
- The sum of all mass and mole fractions in a given solution or compound is always one!
Mole Fractions from Mass Fractions

1. Calculate mass fraction of each substance in solution
2. Divide mass of substance by molecular weight to calculate moles of individual substances.
3. Mole fractions of each substance calculated using total number of moles.
More Chemical Engineering Basics

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Vapor Pressure

- Vapor (or saturation) pressure: pressure that a substance evaporates from liquid to vapor at given temperature
- Calculated using Antoine Equation:

$$\log P_{\text{sat}} = A - \frac{B}{T + C}$$

$P_{\text{sat}}$ = saturated pressure (mm Hg)
A, B, and C = constants
T = boiling point temperature (K)

Vapor Pressure

- Pure substances have one unique saturation pressure for each given temperature
- Point at which vapor-liquid equilibrium is achieved
- For mixture, use Antoine equation but solution is a mixture of all of the substances
- Saturation pressure will vary depending on concentration

Bubble Point and Dew Point

- For mixtures, the bubble point and dew point temperatures are calculated first
- Bubble point: point where first drop of liquid mixture begins to vaporize
- Dew point: point where first drop of vapor begins to condense

https://scied.ucar.edu/sites/default/files/images/long-content-page/800px-Green_Grass_With_Dew_0.jpg
Raoult’s Law

Used to determine composition of vapor and liquid phases in a mixture:

\[ yP = xP_{\text{sat}} \]

- \( y \) = vapor mole fraction
- \( x \) = liquid mole fraction
- \( P \) = system pressure
- \( P_{\text{sat}} \) = vapor pressure

Raoult’s Law Plots

\( P_{xy} \) and \( T_{xy} \) plots are made to model Raoult’s Law

Measurements Used to Analyze Reactions

- **Efficiency**: actual or experimental outcome over the theoretical or calculated outcome for a given situation
- **Conversion**: ratio of the amount of reactant consumed to amount of reactant fed to process
  - Ideal conversion is 1
  - When conversion is high, the reaction favors the products
- **Yield**: ratio of desired product formed to total amount that could have been produced
  - Ideal yield is 1
  - Used to determine if side reactions occurred

Measurements Used to Analyze Reactions

- **Purity**: degree to which a substance is unmixed or diluted with extra material
  - Percentage of mass of substance to mass of impure substance
  - Ideal value is 100%
- **Selectivity**: ratio of desired product formed to undesired product formed
  - Extent to which a mixture separates into desired and undesired products
  - Ideal value is 1
Heat of Reaction

- Unit of measurement to calculate change in enthalpy of reaction at a constant pressure (\(\Delta H\))
- Enthalpy: thermodynamic property that measures total heat content of the system
  - Measures amount of energy released or produced in a reaction

\[
H = U + PV
\]

- \(H\) = enthalpy (kJ/kg)
- \(U\) = total energy of the system
- \(P\) = pressure of the system
- \(V\) = volume of the system

Hess’s Law

- Heat of formation (\(\Delta H_f\)): tabulated value for most pure substance
  - Value unique to each substance
  - Used to calculate the heat of reaction
- Hess’s Law Equation:

\[
\Delta H = \sum \Delta H_f \text{ products} - \sum \Delta H_f \text{ reactants}
\]

State Versus Path Functions

State functions: chemical engineering measurements and functions that rely on the state of a system at a given time
  - Examples: temperature, density, internal energy, enthalpy, and entropy

Path functions: measurements that are determined based on the path that was taken in order to achieve the current state
  - Examples: work, heat, heat of reaction

Microsoft Excel

- Used to analyze many sets of chemical engineering data
- Important functions:
  - Input raw data
  - Evaluate equations
  - Create plots
  - Look at plots using trend lines
- You will have an Excel lab to learn some basic features of Microsoft Excel
Reactions

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What is a chemical reaction?
- The rearrangement of molecule structures resulting in new molecules
- Matter cannot be created or destroyed
  - In some form, reactant elements must be present in products
- Chemical reactions generate everyday products
  - Laboratory/pilot scale or large factories

Reversibility
- Reactions can be reversible or irreversible
- Reversible
  - Can return to original state without altering surroundings
- Irreversible
  - Permanently changes system or surroundings

Reaction Equilibrium
- Equilibrium determines reversibility of reaction
  - Depends on reactants or products being favored
- Process reversibility
  - Not constant
  - Typically changes with temperature
Reaction Efficiency

- Extent of reaction
  - Determines efficiency of reaction
  - Measures how much of the reactants are converted to products
- Units
  - Mole

Extent of Reaction

- Limiting reactant
  - Followed through reaction to measure conversion
- Other reactants
  - Extent of reaction calculated using limiting reactant
  - Uses stoichiometric ratio with regard to limiting reactant

**If:**  \( aA + bB \rightarrow cC + dD \)

Then:
- \( N_A = N_{A0} - \xi \)
- \( N_B = N_{B0} - \left( \frac{b}{a} \right) \xi \)
- \( N_C = N_{C0} + \left( \frac{c}{a} \right) \xi \)
- \( N_D = N_{D0} + \left( \frac{d}{a} \right) \xi \)

These equations use the limiting reactant extent of reaction to solve final amounts of substances

Controlling Reaction

- Non-reactive substances are often added to reactions
  - Helps control temperature and pressure
  - **Avoids explosions**
- Inert gases and other non-reactive substances
  - Don’t affect kinetics or reactions
  - Also used to alter volume
  - Typically \( N_2 \) or noble gas
Combustion

- Specific reaction involving burning fuels with oxygen
  - Releases energy used to heat or power machines
  - Oxygen must be present
  - Ex. Fire
  - Smothering or putting out fire?
    - Oxygen supply is cut off

- Always exothermic reaction
  - Release heat
  - Almost anything organic will burn or combust
    - Made of carbon, hydrogen, and oxygen
  - When organics combust
    - Products are CO$_2$ and H$_2$O

Combustion

- Classifications of combustion reactions
  - Lean or rich
  - Lean reaction
    - Contains less oxygen than ideal stoichiometric ratio
  - Rich reaction
    - Contains more oxygen than ideal stoichiometric ratio
    - Ex. Outdoor bonfire

Fermentation Reaction

- Another common reaction is fermentation
  - Used in production of alcoholic beverages
  - Involves yeast in either aerobic or anaerobic conditions
    - Produces alcohol from sugars
  - Reaction also occurs in other places
    - Bacteria
    - Muscles in human body
Fermentation Reaction

Yeast eats the sugar resulting in carbon dioxide and alcohol released

\[ C_6H_{12}O_6 \rightarrow 2 C_2H_5OH + 2 CO_2 \]

Runaway Reactions

• Large exothermic reactions can be problematic
  • Too much heat and energy is given off
  • Result of a runaway reaction is typically an explosion
• Energy and heat builds up
  • Must be released in some way
  • Pressure increases too much and ruptures vessel

Biodiesel Reaction

• Biodiesel is produced by two reactions
  • Transesterification and esterification
• Esterification
  • Alcohol and acid produces ester and water
  • Esters are compounds with multiple oxygens connected to a central carbon group

Biodiesel Reaction

• Oils or fats are reacted with alcohol
  • Vegetable oil or animal fats
  • Methanol or ethanol
• Reaction specifics
  • Feed oils must be treated and remove water
  • Acid catalyzed esterification can produce biodiesel
  • More environmentally friendly than common fuel types
Biogas

• Another eco-friendly reaction for energy and fuel
  • Creation of biogas from waste products
  • Mixture of CO$_2$ and CH$_4$
• Combusted with oxygen to create energy
  • Many different fermentation or digestion reactions create biogas
  • Can be substituted for fossil fuels
Thermodynamics

What is thermodynamics?
- Scientific study of heat and other forms of energy
- Explains many different phenomena
  - Why hot items cool off
  - How motion is turned into power
  - Differences in height can create energy

Laws of Thermodynamics

Zeroth Law
- If 2 bodies are at the same temperature as a 3rd object
- The 2 bodies are then the same temperature
- What does this really mean?
  - All temperature measurements are consistent within the same units

First Law
- Energy and matter cannot be created or destroyed
- Energy and matter can take many different forms
- How is this useful?
  - This phenomena is used to solve many complex equations
Vapor Pressure

Log \( P_{sat} = A - B / (T+C) \)

- Vapor pressure of a chemical
  - When particles will begin to move from liquid to vapor
- Cox charts
  - Tabulated vapor pressure information
  - 2 vapor pressures and temperatures can be used with linear analysis to relate vapor pressure

Humidity

- Some engineering problems rely on humidity
- One way to solve these problems is a psychrometric chart
- Chart depicts many different relationships
  - Humidity
  - Temperature
  - Adiabatic Saturation

Humidity

- The amount of water vapor in the air
- Humidity ratio is given on the right hand y-axis
  - Ratio is amount of moisture per amount of dry air
- Dry bulb temperature is x-axis
  - Dry bulb is the regular temperature of the air measured freely

Saturation

- Wet bulb temperature
  - Temperature reading on thermometer if fully saturated
- Air saturation
  - 100% capacity for water vapor (100% relative humidity)
- Wet bulb can be calculated for given dry bulb temperature
  - Follow humidity ratio line to 100% saturation curve
Relative Humidity

\[ H_R = \frac{P_p}{P^*(T)} \times 100\% \]

- \( H_R \) is relative humidity
- \( P_p \) is the partial pressure of water
- \( P^*(T) \) is the vapor pressure

Mole fraction can be calculated when given partial pressure

\[ X_a = \frac{P_a}{P} \]

- \( X_a \) is mole fraction
- \( P_a \) is partial pressure of \( a \)
- \( P \) is total pressure of the system

Absolute Humidity

\[ H_a = \frac{m_v}{m_g} \text{ mass vapor} \]
\[ \text{mass dry gas} \]

Laws of Thermodynamics

- Second Law
  - Entropy of an isolated system will tend to rise over time

- Entropy
  - Thermodynamic quantity representing degree of disorder

- Measurement of system's inability to convert heat into work
  - Units of entropy are KJ/Kg K
  - Abbreviation is \( S \)
Laws of Thermodynamics

• Third Law
  • As temperature of system approaches absolute zero (0K)
  • Entropy of system approaches a constant minimum
• What does this mean?
  • Systems are most stable at lower temperatures

Enthalpy

• Thermodynamic property that measures total heat content
  • Defined as total energy plus product of pressure and volume
  \[ H = U + PV \]
• Very useful measurement for heat and energy change
• Derived from an assumption of constant pressure

Enthalpy

• Enthalpy for different chemicals can be found in literature
  • Wide variety of temperatures and pressures
• For water, these tables are known as steam tables
• Include many different phases
  • Compressed liquids
  • Saturated liquid
  • Saturated vapor
  • Superheated vapor

Steam Tables

• Useful when working with Vapor-Liquid Equilibrium (VLE)
• VLE is a phase equilibrium with multiple components
  • Most basic is just one chemical
• Present in multiple phases
  • Vapor, liquid, or both
Phase Diagrams

- Phase diagrams show the relationship among variables
- Three common phase diagrams
  - Pressure-Volume with constant temperature
  - Pressure-Temperature with constant volume
  - Temperature-Volume at constant pressure
Phase Diagrams

- Phase diagrams depict trends
  - At constant $T$, $P$ decreases and $V$ increases
  - At constant $V$, $P$ increases and $T$ increases
  - At constant $P$, $T$ increases and $V$ increases
- Diagrams also help determine the phase of the chemical

Terminology

- Isothermal
  - Temperature of system is constant
- Isobaric
  - Pressure of system is constant
- Isochoric
  - Volume of system is constant

Terminology

- Isentropic
  - Entropy of system is constant, also adiabatic and reversible
- Isenthalpic
  - Enthalpy of system is constant
- Adiabatic
  - No energy enters or leaves the system

Non-Ideal Gases

- Ideal Gas Law
  - $PV = nRT$
- Density must be low and weak intermolecular forces
- Most real world gases do not meet these conditions
  - Must use correlations and equations to predict behavior
Equations of State

• Algebraic equations that predict the behavior of gases
  • Ideal or non-ideal
  • Used to determine temperature, pressure, or volume
  • 2 of the 3 characteristics must be known
• There are many different equations of state
  • Even for complicated systems

Equations of State

• Equations of state rely on rigorously calculated constants
  • Constants are for specific substances
  • Constants are usually called parameters
  • Constants are developed through research methods
  • Data is then fit to parameters to find the line of best fit

Equations of State

• Two common equations of state
  • Soave
  • Peng-Robinson
• These equations of state were developed as an extension of the ideal gas law that applies to non-ideal gases

Gas-Liquid Phase Reactions

• EOS are very useful for gas-liquid phase reactions
• Reactions that take place in both gas and liquid phases
  • Typically called vapor-liquid equilibrium (VLE) problems
• Basic information on the system will be given
  • Pressure, temperature, or composition is then determined
  • Either vapor or liquid phase
Gas-Liquid Phase Reactions

• One pure component systems are fairly simple
  • Equilibrium will occur between vapor and liquid
    • This occurs at its saturation pressure
  • Temperature or saturation pressure can be calculated
    • Specific volume of liquid and gas can be determined
    • Enthalpy and entropy can be determined from steam tables

Gas-Liquid Phase Reactions

• Multi-component systems become more complicated
  • Contains at least 2 unique components in both phases
  • Necessary to determine saturation pressure of all components using Raoult’s Law
    \[ yP = xP_{sat} \]
    • \( y \) is vapor mole fraction
    • \( x \) is liquid mole fraction
    • \( P \) is system pressure
    • \( P_{sat} \) is the vapor pressure

Gas-Liquid Phase Reactions

• Analysis can be done for all components
  • Vapor pressure must be calculated
  • In 2 component system, once \( x \) and \( y \) for one component is calculated
    • \( x \) and \( y \) for the second component can be found easily
      • \( x_A + x_B = 1 \)
      • Also hold true for \( y \) values

Gas-Liquid Phase Reactions

• Important to not which component is more volatile
  • Lower boiling point
  • This component will be more abundant in the vapor phase
  • The inverse holds true for liquid phase
Gas-Liquid Phase Reactions

- Multi-component systems are used in alcohol production
  - Distillation of water and ethanol
- More valuable component, alcohol, is transferred from the liquid to the gas and harvested in another container
  - Can be done for most VLE systems

Gas-Liquid Phase Reactions

- Azeotropes
  - VLE systems that have strong deviations from ideal behavior
  - Composition of boiling liquid is the same as condensing vapor
- Troublesome in distillation processes
  - Relies on difference in boiling points
  - Azeotropes boil at one constant temperature
- A different separation technique must be used

Thermodynamic Applications

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Thermodynamic Efficiency

- Measure of energy that is actually converted to usable work
  - Ratio of usable work to theoretically created energy
  - Unit is percentage (%)
- Cycles deal with the second law of thermodynamics
  - Efficiency cannot be 100%
Carnot Cycle

• Heat engine that expresses the fundamentals of the second law
• Developed by French engineer
• Consists of a pump, boiler, turbine, and condenser
• Each process is reversible
• Heat is exchanged with the surroundings through the condenser and boiler

Carnot Cycle

• Pump
  • Adiabatic compression
  • High temperature boiler
  • Isothermal heat addition in adiabatic expansion process
• Turbine
  • Exchanges heat and motion for work
• Condenser
  • Isothermal heat rejection of low temperature

Carnot Cycle

• Reversible at each step
• Whole cycle is considered reversible
• Reverse Carnot cycle is a refrigeration cycle
  • Compressor
  • Evaporator
  • Pump
  • Condenser

Carnot Cycle

• First step is an isothermal heat transfer
• Followed by reversible adiabatic, isentropic process
• Next, an isothermal heat transfer
• The last step is an isentropic process
Engines

- Internal combustion engines have controlled combustion
  - Drive piston to create mechanical work
  - Used in cars and house heating
- Combustion is done in a specific chamber
  - Can be converted to mechanical work or pressure gas in a piston
- Created by Nikolaus Otto and resembles modern engine

Otto Cycle

- Simulates the spark ignition internal combustion engine
  - Precursor to internal combustion we see today
  - Consists of piston moving from top to bottom
  - Expansion and compression processes

Otto Cycle

- Compression
  - Step is adiabatic and isentropic
- Combustion
  - Step is isochoric but generates heat
- Expansion
  - Process is adiabatic and isentropic
- Heat rejection
  - Volume is held constant but heat decreases

Diesel Cycle

- Very similar to Carnot cycle with a few differences
  - Combustion process consisting of internal combustion engine
- Fuel is ignited during compression stage
  - Otto cycle ignites fuel-air mixture using a spark plug
- Diesel engine used in cars, planes, power, and trains
  - Operates on assumption of constant pressure
Separations

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Separations

- Separation of chemical compounds
  - On of the most important unit processes in chemical engineering
  - Products of reactions are split into usable, sellable products
- Goal is to separate valuables from waste streams
  - Unused reactants will be recycled in process
  - Processes can be uni-step or multi-step depending on difficulty

Distillation

- Separation technique used to produce spirits
  - Alcohol is distilled from water to increase concentration
- Used in the production of gasoline and other oil products
  - Series of separation processes separate heavy and light hydrocarbons
  - Light hydrocarbons
    - Produce gasoline, kerosene, motor oil, and other things
  - Heavy hydrocarbons
    - Either cracked down or used to produce diesel
- Operates on the principle of differing boiling points
  - Feed is liquid and heated to boiling point of more volatile component
  - More volatile component will evaporate more quickly
  - Also called the light key
- Less volatile key will remain in the liquid phase at the bottom
  - Selectivity determines how much separation will occur
Distillation

• Inlet is usually fed at a specific height on the column
  • Tray position is determined by many optimization equations
• Number of trays in the column is also unique
  • Determined by optimization to improve separation
• Vapor liquid equilibrium is reached at each tray
• McCabe-Thiele diagrams are used to determine optimum reflux ratio, compositions, and feed stage

Distillation Columns

• At the top, vapor is fed to a condenser
  • Condensed liquid is recycled to column or pumped out as product
  • The amount released as product vs returned is the reflux ratio
  $$r = \frac{\text{product released out}}{\text{distillate returned to column}}$$
• At the bottom, liquid is fed to a reboiler
  • Liquid is heated to vapor-liquid mixture
  • Can either be recycled or released as a finished product

Distillation Columns

• Distillation columns are typically run continuously
  • Feed is constantly added and products removed from system
• Only time shutdown occurs
  • Cleaning, regular maintenance, or in case of disaster
• Continuous distillation is economically beneficial and safer
  • Most dangerous during transient stages, start up and shut down

Batch Distillation

• Batch distillation can be used for smaller operations
  • Done in laboratory scale production or pharmaceuticals
• Batch distillation is how moonshine is created
• A set amount of feedstock is added
• Two liquids are boiled together
  • Vapors are collected and cooled resulting in higher concentrations
• Other separation techniques are sometimes needed
Adsorption

- Separation technique that relies on adhesion of certain molecules to a surface
- Specific surfaces are used due to large void fractions
- Molecules will adsorb allowing the rest of the fluid to pass
- Surface based process
- Exothermic process that increases until equilibrium
  - Equilibrium reached when the surface become saturated
- Used in water purification and pharmaceuticals

Absorption

- Process where a fluid is dissolved by a liquid or solid
  - This is the absorbent
- Components will transfer from gas phase to liquid or solid
  - Absorption occurs in the bulk of the fluid
  - Endothermic process that occurs at uniform rate
- Used to many different applications
  - Separate gas mixtures, remove impurities, space cooling, and carbonation of beverages

Stripping

- Physical separation where a liquid or vapor stream removes one or more components from a mixture
- Basically the opposite of absorption
- Stripping fluid flows counter current to the mixture
  - Typically occurs in a packed bed or tray column

Extraction

- Mixture is brought into contact with a solvent in which only the desired substance is soluble
- 2 phases that do not mix are used to separate a substance
  - Substance goes from one phase to another
- Typically done using an aqueous and organic phase
Membrane

• Fluid is flowed through a semi porous membrane
  • Only certain particles can pass through membrane wall
• Dependent on pore size of membrane
  • Smaller molecules will be able to pass through membrane
• Relies on pressure drop through walls for separation
Introduction to Fluid Mechanics

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Fluid Mechanics

• Branch of chemical engineering dealing with fluids: pressure, flows, and energy

• Assumptions:
  • Energy and mass can neither be created nor destroyed
  • Fluids can be gases or liquids
  • Density is constant for chemicals under specific circumstances

Control Volume

• Control volume: set amount of space for a system within the larger universe of space
• Defines the boundary of the system in question
• Helps identify what boundaries the fluid is entering and exiting within the system
• Can be still or in motion with the fluid

Shear strain rate: rate of change of velocity of fluid over a distance

Fluid Properties

Shearing stress: stress or pressure developed within a fluid due to force on a specific area

\[ \tau = \frac{F}{A} \]

\( \tau \) = shearing stress (Pa)
\( F \) = force (N)
\( A \) = area (m²)

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http://homepages.cae.wisc.edu/~chinwu/CEE310_Fluid_Mechanics/splash.jpg
Fluid Properties

- **Viscosity (\( \mu \)):** measure of the fluidity of a fluid
  - Quantifiable measurement of thickness/stickiness of a fluid
  - Example: water is significantly less viscous than honey

- **Additional properties:**
  - Pressure (absolute and gauge)
  - Vapor pressure
  - Area

Classifying Fluids

- **Newtonian fluid:** fluid whose shearing stress is linearly related to strain rate
  - As stress increases, strain increases or decreases proportionally
  - Viscosity only dependent on temperature
  - Examples: water, honey, organic solvents

- **Non-Newtonian fluid:** viscosity dependent on shearing rate
  - No direct correlation to shearing rate and stress
  - Examples: ketchup, toothpaste, blood, paint

Fluid Statics

- **Fluid statics:** the study of fluids at rest
  - No shearing stress, only pressure acting on fluid

- **Pascal's Law:** the pressure of a fluid in an enclosed volume is the same throughout the fluid

\[
\frac{F_1}{A_1} = \frac{F_2}{A_2}
\]

- \( F = \) force (N)
- \( A = \) Area (m\(^2\))

Hydrostatic Pressure

- **Hydrostatic pressure:** pressure exerted by a fluid at rest due to gravity alone; changes with depth

\[
P = \rho g z
\]

- \( P = \) pressure
- \( \rho = \) density of the fluid
- \( g = \) acceleration due to gravity
- \( z = \) height

\[
\Delta P = \rho g \Delta z
\]

- \( \Delta P = \) pressure change
- \( \rho = \) density of the fluid
- \( g = \) acceleration due to gravity
- \( \Delta z = \) height change
Hydrostatic Force Calculation

- Hydrostatic forces on a submerged plane surface
- Important when designing dams, ships, and fluid storage tanks

\[ F = \rho g h A \]

- \( F \) = force
- \( \rho \) = density of the fluid
- \( g \) = acceleration due to gravity
- \( h \) = height
- \( A \) = total surface area of plane

Manometer

- Manometer: device that uses vertical or inclined liquid columns to measure pressure of a fluid

Fluid Dynamics

- Fluid dynamics: study of fluids in motion
- Bernoulli’s Equation:

\[ P_1 + \frac{1}{2} \rho v_1^2 + \rho g z_1 = P_2 + \frac{1}{2} \rho v_2^2 + \rho g z_2 \]

- \( P \) = pressure
- \( \rho \) = density
- \( v \) = velocity
- \( g \) = gravitational acceleration
- \( z \) = height

Dimensionless Numbers

- Dimensionless number: a number in which all of the units cancel out
- No physical dimensions for these numbers
- Used to analyze certain situations by creating models or simulations
- Examples: Reynold’s number and Biot number
Reynold’s Number

- **Reynold’s number**: dimensionless number that is a ratio of internal forces to viscous forces
- Used to predict flow patterns

\[ Re = \frac{\rho v D}{\mu} \]

- \( Re \) = Reynold’s number
- \( \rho \) = fluid’s density
- \( v \) = average velocity
- \( D \) = pipe diameter
- \( \mu \) = viscosity

Fluid Flow

- **Laminar flow**: one-dimensional, orderly flow that occurs at low velocities
  - \( Re < 2100 \)
- **Turbulent flow**: three-dimensional, unpredictable flow that occurs at high velocities
  - \( Re > 4000 \)
- **Transitional range**: between laminar and turbulent flow
  - \( 2100 < Re < 4000 \)

Friction Factor

- **Friction factor**: used to estimate pressure drop for flow in a pipe of a given surface roughness

- Laminar flow:
  \[ f = \frac{64}{Re} \]
  \( f \) = friction factor
  \( Re \) = Reynold’s number

- Turbulent flow: use the Moody Diagram
Heat Transfer

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What is Heat?
• Transfer of energy from a hotter object to a colder object
• Form of energy
• Always flows from hot to cold
• Typically focuses on flow through a pipe (internal flow) or over a surface (external flow)
• Used to describe temperature of an object
• Temperature and heat are related but not interchangeable
• Think of how heat transfer from hot coffee to the air

Heat
• Units: Joule [J] (SI) or British Thermal Unit [BTU] (English)
• Rate of heat transfer units: Watt [W] or J/s
• Driving force is the temperature gradient
• All forms of energy can be converted to heat and vice versa
  • Kinetic energy: friction gives off thermal energy due to decreasing velocity
  • Electrical energy: space heaters or lights
  • Chemical energy: food converted in body to keep us warm

Methods of Heat Transfer
Conduction: occurs via direct contact of colder molecules or particles with hotter ones
Convection: occurs when warmer areas of a fluid rise to colder areas
Radiation: occurs when heat transfers via electromagnetic waves
Conduction

- Objects must be touching for heat transfer to occur
- Typically occurs within solids
- Metals are good conductors while plastics are poor conductors
- Conductive heat transfer equation:
  \[ \dot{Q} = \frac{kA(T_H - T_C)}{d} \]
  - \( \dot{Q} \) = heat transfer rate
  - \( k \) = heat transfer coefficient
  - \( A \) = area of heat transfer
  - \( T_H \) = hotter temperature
  - \( T_C \) = colder temperature
  - \( d \) = distance/thickness of border

Convection

- When hot fluid moves, cold fluid takes its place
- Newton’s Law of Cooling:
  \[ \dot{Q} = hA(T_W - T_\infty) \]
  - \( \dot{Q} \) = heat transfer rate
  - \( h \) = convective heat transfer coefficient
  - \( A \) = area of heat transfer
  - \( T_W \) = temperature of the fluid
  - \( T_\infty \) = temperature of the surroundings

Radiation

- Does not require medium or contact between objects
- Example: Sun’s rays heating Earth
- Radiative heat transfer equation:
  \[ \dot{Q} = \varepsilon\sigma(T_s^4 - T_{Sur}^4)A \]
  - \( \dot{Q} \) = heat transfer rate
  - \( \varepsilon \) = power emitted by object
  - \( \sigma \) = Stefan-Boltzmann constant \( 5.6703 \times 10^{-8} \)
  - \( T_s \) = absolute temperature of surface (K)
  - \( T_{Sur} \) = absolute temperature of surroundings (K)
  - \( A \) = area of the emitting body

Heat Exchangers

- Allow two process streams to exchange thermal energy
- Hot flow cooled by colder flow and vice versa
- Typically have an input stream of pure water used to heat or cool the system
Types of Heat Exchangers

- Radiators: liquid-air heat exchangers
- Liquid-liquid heat exchangers are run counter-current
  - Inlet streams enter from opposite sides of exchanger
- Co-current heat exchangers: inlet streams on the same side of exchanger
- Shell in tube or floating head

Heat Exchanger Equations

Heat transfer equation:

\[ Q = U A (\Delta T)_{LMTD} \]

\[ (\Delta T)_{LMTD} = \frac{\Delta T_{in} - \Delta T_{out}}{\ln \left(\frac{\Delta T_{in}}{\Delta T_{out}}\right)} \]

- \( Q \) = heat transfer rate
- \( U \) = heat transfer coefficient
- \( A \) = heat transfer area
- \( (\Delta T)_{in} \) = temperature difference between inlet fluids
- \( (\Delta T)_{out} \) = temperature difference between outlet fluids
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Static vs Dynamic System
- Static system
  - System that is unmoving
- Dynamic system
  - System that is in motion
- Can be applied to batch vs continuous reactors
  - Batch is static with no flow in or out
  - Continuous is dynamic with flow in and out

Steady state vs transient
- To reach steady state, a transient period must occur
- Steady state
  - Variables that define a system do not change with time
- Transient
  - Contain variables that will change with time
  - Engineers often develop systems assuming steady state
  - Assumptions are altered for start up and shut down
  - Simplify mass and heat transfer equations

Control Systems
- Controls systems are necessary for large chemical processes
  - Monitor temperature, pressure, volume and other characteristics of the system
- If a variable is outside its allowable range
  - Alarms will go off and the system will readjust itself
- Systems vary in complexity
  - Simple control open/close valve
  - Complex system monitoring temperature and adjusting cooling water flow
Control Systems

• Basic types of controllers
  • Feedback and feedforward
  • Feedback
    • Measures output ahead of controller and adjusts inlet accordingly
  • Feedforward
    • Disturbance is measured and valve is adjusted accordingly

Pumps

• Mechanical devices that run on electricity and power
  • Used to increase pressure of liquids
  • Move liquids from place to place or unit to unit
  • Turn electrical energy into mechanical energy
  • Many different applications
    • Water cooling and filtration, cars, oil and natural gas and others
  • Different types
    • Positive displacement and centrifugal pumps

Compressors

• Essentially pumps for vapors
• Liquids cannot be used as they are considered incompressible
• Convert electrical energy into mechanical work
  • Used to decrease the volume of a gas
• From ideal gas equation
  • When volume of a gas decreases, pressure increases

Chemical Processing Plants

• Five major sections of processes
  • Reactor feed preparation
  • Reactor
  • Separator feed preparation
  • Separator
  • Recycle structure
• Carefully fit together to form a functioning plant
Reactor Feed Preparation

• Consists of the flow of reactants from storage tanks to the reactor
• Reactants are brought up to reaction specifications
  • Optimal temperature and pressure
• Accomplished with an array of heat exchangers, pumps, and compressors

Reactor

• Section where reaction takes place
• Products are created
• Reactants leave feed prep and enter reactor
• Reaction is carried out in one or multiple reactors
  • Determined by type, size of reaction, and reaction kinetics
• Reactor selected based on desired end results

Separation Feed Preparation

• After the reaction has taken place
• Objective is to bring streams to separation specifications
  • Optimal temperature and pressure
• Changes achieved through an array of heat exchangers, pumps, and compressors

Separation

• Pure products are separated from unused reactants and waste
• Type of technique can vary
  • Depends on what chemicals are present
• Most common is distillation column
• Multiple techniques can be combined in series
Recycle Structure

- Chemicals leave separation and sent into recycle system
  - Deals with unused reactants
  - Pass through heat exchangers, pumps, and compressors
  - Reach optimal temperature and pressure
  - Fed back into reactor to cut raw materials costs

Breweries

- Works in similar fashion to a chemical plant
  - Reactor prep is all steps leading up to fermentation
    - Fermentation is the reaction step
  - Separations step is filtering the beer
    - Removing unwanted particles using plate and frame filtration
  - There is typically no recycle structure in a brewery

Whiskey Production

- More similar to a chemical plant than a brewery
  - Reactor prep is all steps leading up to fermentation
    - Fermentation is the reaction step
  - Separation prep is pumping and heating the water and alcohol
    - Separations step is a distillation column or pot still
  - There is typically no recycle structure unless water is recycled
University of South Carolina
BBB Chemical Engineering Department
Introduction to Excel and Plotting

Introduction:

A spreadsheet is a useful tool in organizing experimental data and performing both basic and complex mathematical analysis. Learning to efficiently use excel is a critical part of basic chemical engineering practices. Learning how to use excel and create spreadsheets in the beginning of this course will help you later on during laboratory analysis. Although basic calculations can easily be done using standard calculators, excel is useful in repetitive calculations, generating plots, and completing more complex mathematical analysis. In short, learning to use excel will greatly simplify your life both in this course and in future endeavors. Spreadsheets are commonly used in the fields of engineering, natural sciences, public health research, accounting, finance, and medical research to name a few.

Objective:

The goal of this lab is not simply to give you a list of excel commands to explore and memorize. Instead the purpose of this study is to walk you through the basic functions of excel that will become very useful to you as you move through this course. As a result of this lab, you will have a basic understanding of simple excel functions including inputting data, generating plots, referencing cells, and creating repetitive equations.

Procedure:

Organization of a spreadsheet-

1. Go to your programs menu on your computer. Search for Excel. Click the Microsoft Excel Icon (green) to open program.

You should now see a blank page with many small boxes. The technical term for each box in a spreadsheet is a cell. Cells can be referenced using a combination of a letter and a number. The Letter represents which column the cell belongs and the number represents the row.

2. Locate cell D6 on your spreadsheet. Note that this cell is the fourth column and the sixth row.
Excel Fundamentals

One function of a spreadsheet is that it can be used as a basic mathematical calculator. However, better than a calculator, it is able to save your results in various boxes for later use. All calculations or equations in excel must begin with an equal (=) sign. This indicates to the program that you are about to perform a calculation. Below is a table of some common mathematical operations and their commands in excel:

<table>
<thead>
<tr>
<th>Operation</th>
<th>Excel Command</th>
</tr>
</thead>
<tbody>
<tr>
<td>Addition</td>
<td>=B1+C1</td>
</tr>
<tr>
<td>Subtraction</td>
<td>=B1-C1</td>
</tr>
<tr>
<td>Multiplication</td>
<td>=B1*C1</td>
</tr>
<tr>
<td>Division</td>
<td>=B1/C1</td>
</tr>
<tr>
<td>Exponent</td>
<td>=B1^C1</td>
</tr>
</tbody>
</table>

Now we will work some basic examples using these operations.

Example 1

1. Type 8 into cell A1 and 3 into cell B1.

2. In cell C1, add 8 and 3 together.

3. In cell C2, subtract 3 from 8.
4. In cell C3, multiply 8 by 3.

5. In cell C4, divide 8 by 3.

6. In cell C5, raise 8 to the power of 3.
Keep these results recorded. Note that each solution has a different amount of significant figures. This can be altered with the format cells feature. With this feature it is possible to convert the numbers within the cells to the correct number of significant figures, scientific notation, fractions, percentages, and many other formats that you may need.

7. Select cells C1-C5.
8. Right click on one of the selected cells and pull up the menu.
9. Select the format cells option.
10. Select the number category.
11. Enter 2 decimal places and click ok.

All of your solutions should now have only 2 numbers after the decimal point.

Referencing Cells-

When typing equations into blank cells, it is not necessary to retype numbers that are already present. Instead, all you have to do is click on the reference cell containing the number you wish to use (or simply type its reference number into the equation).

1. Multiply the result of C3 by C4 and then divide by C5. Reference each of these cells in the calculations, not simply their respective numbers.
When copying the value from one cell to another, you can click the standard copy (CTR + C or right click copy) and then paste (CTR + V or right click paste). If there is no equation in the cell, then the value will be pasted. If there is an equation present in the copied cell, then the formula for the equation will be pasted. This could result in different answers as different cells may be referenced. Doing this automatically adjusts which cell if being referenced in relation to the new cell. If you wish to copy just the value of a cell, copy the cell (CTR + C), then right click and select paste special > value. Additionally, adding a $ sign in front of both the letter and number in a cell reference allows for just the cell value to be copied and pasted.

2. Redo the previous calculations using referenced cells where ever possible. The output of the 2 tables should be identical.
3. Change the 8 and 3 in the second table to 6 and 7. How did the tables change?

Referencing cells becomes very important when you make mistakes in calculations as it is only necessary to change one cell instead of all the calculations. This one simply change will them correct all subsequent calculations.

Entering Data into Excel-

Often times it is necessary to manually input experimental data into excel in order to further analyze. This is a very simple operation. Simply select the column that you wish to use and label it with the name or variable for this specific data. Enter all the data values for this variable. Repeat these steps for each variable data as necessary.

Graphing-

By now you have seen the organizational benefits of excel. In addition, to its excellent ability to keep track of data and perform calculations, excel can also be used to generate graphs. Graphs are essential in chemical engineering as they enable you to present large amounts of data in a concise manner that immediately draws the reader’s attention to a trend or pattern. Unfortunately, the format and types of default graphs that excel makes are not the most useful for engineering or scientific purposes. Here are some general guidelines for making a good graph (note these are tips, not mean to be performed for the purpose of this lab):

- Most applications will use an x,y scatter plot
  a. Go to the insert tab on the top of your spreadsheet tool bar
b. Under the charts category, select the x,y scatter plot (it will look like a bunch of points on a x,y axis)

Excel can plot points or it can connect them with lines (smoothed or straight).

You can add trendlines or best fit lines to the plotted data by:

a. Select your chart area
b. Under the design tab on excel, select the add chart element option on the left hand side of the tool bar
c. This will provide a drop down menu of options. This is also where you can select to add axis labels (ALWAYS NECESSARY)
d. For trendlines, select the trendline option.
e. This will drop down an additional menu. Select which option best fits the plotted data.
f. If the trendline equation is needed, you must select more trendline options and check the box to display equation on graph.

Unless you are using a color printer, do not use different colors as the main way to differentiate data sets. Instead use different symbols by:

a. Select the data set that you wish to update by right clicking on one point from the set.
b. This will bring up a menu of options, select format data series.
c. Go to series options and select marker options.
d. Scroll down to built-in and select which marker size you desire. This will update the whole data set.

Example 2:

In this exercise, we will plot graphs using excel. To plot a graph, we need data that can be graphed. We will use a simple line equation, \( y = mx + c \) to generate the data for this graphing exercise. In this equation, \( m \) is the slope of the graph and \( c \) is the intercept. To generate the data, we will assume the x values in the range \([0, 10]\). Also, the slope of the line, \( m \), is 0.1 and the intercept, \( c \), is 2. We can utilize Excel's copy-paste method to quickly generate the data.

1. Create a new tab in your spreadsheet by clicking on the plus symbol next to Sheet 1 in the bottom left corner of the page. Rename Sheet 2 to E2 and Sheet 1 to E1.
2. Set up the Excel spreadsheet as shown below.
3. Enter the formula “=$B$2*A4+$B$1” in cell B4. We use absolute referencing for both c and m because we do not want them to change when we copy-paste the formula. Absolute referencing refers to the $ symbols that we have placed before the letter and number for the reference cell. This is done so that the referenced cell will remain the same no matter where on the spreadsheet it is referenced.

4. Copy the formula in cell B4 down to cell B14 to generate all the points for y.

5. Once we have the x and y values, we have sufficient data to plot a graph.


7. Generate a scatter graph with selected cells.

8. Insert a trendline for this plot and display the equation on the graph.

9. Insert a chart title “y vs x” and axis titles “x” and “y”

To generate a graph from multiple datasets, we need to first create the multiple data sets. In this example, we will create these data sets by using the same line graph problem with different slopes. Consider m = 0.1, 0.2, 0.3, 0.4 and 0.5.

1. Recreate the layout from the previous part of example 2 and generate the data for the other 4 lines using the formula \(y = mx + c\).
2. To generate multiple graphs from scratch, we just have to select all the data A3:F3 to A14:F14, click on the insert tab and choose scatter plot.

You can also generate a plot by clicking the insert tab and selecting the scatter plot option. This will generate a blank graph area. Right click on the graph space. This will pull up a menu. Select the select data option. This will open a new window called select data source. Click the add button to add new data sets. Click the series x button and drag down A4:A14. Then click the series Y button and drag down from B4:B14. Do this for all remaining y data sets, adding a new series each time.

3. Change the marker for each of the data sets so that no 2 have the same marker shape.
Introduction to Measurements in the Laboratory

**Introduction:**

Precise and accurate measurements are a crucial part of any science experiment. Important measurements in chemical engineering include, but are not limited to, length, mass, volume, and temperature. In this lab, you will learn how to use various measuring devices to obtain quantitative information about the objects at hand.

To evaluate these measurements, you will use the International System of Measurement (SI). To measure length, you will use the units of meters (m). To measure mass, you will use the units of grams (g). To measure volume, you will use the units of liters (mL). To measure temperature, you will use the units of Celsius (°C). You must also be familiar with the common SI prefixes and how to convert between various units (i.e. kilo- to milli-, etc.).

**Procedure:**

**Part 1: Length**

1. Obtain a meter stick/ruler and cylinder from your TA. *(NOTE: the cylinder will be the same as the one used for the Heat Conduction experiment).*
2. Measure the diameter of the circular face of the cylinder in millimeters and record this measurement in your lab notebook. Be as precise as possible!
3. Measure the length of the cylinder and record it in your lab notebook.
4. Repeat this procedure for each cylinder.

**Part 2: Mass**

1. To measure the mass of an object, you will use a digital measuring scale. Obtain the cylinders you used in Part 1.
2. Go to the digital measuring scale. Make sure that it is plugged in and turned on.
3. Make sure there is nothing on the scale and press the “tare” button. This will ensure that the scale is set to zero.
4. Place the cylinder on the scale and record the mass in grams in your lab notebook.
5. Repeat steps 3 and 4 for each cylinder.

**Part 3: Volume**

1. Obtain a beaker filled with water. Record the volume of the water in mL in your lab notebook. Make sure you record the volume of the liquid at the bottom of the meniscus!
2. Pour all the water from the beaker into a graduated cylinder. Record the amount of water that was transferred into the graduated cylinder in your lab notebook. Once again, make sure you record the volume of the liquid at the bottom of the meniscus.
3. Drop one cylinder from Parts 1 and 2 into the graduated cylinder filled with water. Record the amount of water in the graduated cylinder after adding the cylinder in your lab notebook.
4. Repeat steps 1-3 for each cylinder.
Part 4: Temperature
1. Obtain a centigrade thermometer from your TA.
2. Record the temperature of the room in °C in your lab notebook.
3. Measure the temperature of the water from Part 3. Record this value in your lab notebook.

Analysis:

Part 1: Length
1. Calculate the surface area of the cylinder in meters (Hint: You must convert from mm to m before performing the calculation):
   \[ A = \frac{\pi d^2}{4} \]
   A = area of the surface (m²)
   d = diameter of the circle (m)
2. Calculate the volume of the cylinder:
   \[ V = \pi r^2 h \]
   V = volume of the cylinder (m³)
   r = radius of the circle (m) (hint: radius is equal to half of the diameter)
   h = height of the cylinder (m)

Part 2: Mass
1. Calculate the density of each cylinder by using the mass measurements and the volume calculations from Part 1.
   \[ \rho = \frac{m}{V} \]
   \( \rho \) = density of the cylinder (g/m³)
   m = mass of the cylinder (g)
   V = volume of the cylinder (m³)
2. Calculate the percent difference between each of the cylinders.
   \[ \text{percent difference} = \frac{|\text{cylinder}_1 - \text{cylinder}_2|}{\left(\frac{\text{cylinder}_1 + \text{cylinder}_2}{2}\right)} \times 100\% \]

Part 3: Volume
1. Calculate the percent difference from when the water was transferred from the beaker to the graduated cylinder.
2. Calculate the volume of each cylinder in milliliters.
   \[ V_{\text{cylinder}} = V_{\text{water after cylinder added}} - V_{\text{water before cylinder added}} \]
3. Compare the volume obtained in Part 1 to the volume obtained in Part 3 for each cylinder by calculating the percent differences. **Note**: make sure the units for all of the volumes match before calculating the percent difference (Hint: 1,000,000 mL = 1 m³).
Part 4: Temperature

1. Convert the temperatures you recorded to Kelvin.
   \[ T_{\text{Kelvin}} = T_{\text{Celsius}} + 273 \]

2. Convert the temperatures you record to Fahrenheit.
   \[ T_{\text{Fahrenheit}} = \left( T_{\text{Celsius}} \times \frac{9}{5} \right) + 32 \]
INTRODUCTION

The history of the centrifugal pump can be traced to the late 1600s. However, the modern centrifugal pump came into general use only within the past one hundred years or so. The progress of the development of the centrifugal pump essentially paralleled that of electric motors and modern steam turbines. As these drivers became bigger and more powerful, so did the centrifugal pump. New, better designed pumps are created every day.

The worldwide oil refining and petrochemical industries are the largest users of centrifugal pumps. Applications include fluids that can be (and often are) both flammable and toxic. Centrifugal pumps typically and routinely handle temperatures from −50 to over 700 °F, pressures from vacuum to over 3000 psig, and specific gravities from as low a 0.62 to over 2.0. This wide range of pumping conditions has presented some unique challenges not only to the engineers designing the centrifugal pump (i.e., the manufacturer), but also to the engineers designing the flow system that contains the centrifugal pump (i.e., the end user).

Valves are used to regulate and throttle the flow being supplied by a pump. Many different types of valves have been designed to fit a multitude of applications. One very common type of valve is the globe valve, which has the ability to start, stop and regulate flow; not all valves can do all three tasks. Another popular valve is the ball valve, which, as the name implies, uses a ball with a bore machined through its center to start and stop flow. When this valve is fully open, which is achieved by rotating its stem 90 degrees, the hole in the ball is in line with the flow. One advantage of this design is that there is little or no friction loss in the valve when it is fully open, since the hole is usually the same diameter as the inside diameter of the pipe. However, ball valves are not very good at regulating flow, although they can be used for this purpose.

The proper design of a piping network requires detailed knowledge of the various resistances in the system that the pump must overcome to move a fluid. These resistances are associated with the piping network itself (i.e., fittings, reducers and expanders, and entrance and exit loses), the characteristics of any valves in the network, and any elevation changes in the system. Once the design requirements for the piping network have been calculated, a pumping system is selected to meet the operational criteria of the piping network and the chemical plant, in general.

OBJECTIVES

This laboratory experience will study the performance characteristics of centrifugal pumps. You will observe and collect data on two different pumps, both operating alone and then in series and parallel configurations. This will demonstrate the flow of fluid through pumps. Using Excel, you will generate plots of different flow rates of fluid as well as the pump head at different flow rates.

EQUIPMENT AND SUPPLIES

Centrifugal Pump Experimental Module

Major pieces of equipment in this system include two different centrifugal pumps from Little Giant Pump Co. Refer to manufacturer’s data for more information (attached).
This system also has one 55-gal plastic drum. Numerous 4.5 in. process pressure gauges, current and voltage meters form Omega Inst. Co., and two digital flow meters from G.P.I. Co. are also included. Minor pieces of equipment in this system include numerous fittings and valves. A tape measure and micrometer are also needed and included.

**Operational Procedure**

**Initial Conditions**

Valves V-1, V-2, V-3, V-4, V-6, V-7 and V-8 are closed. The flow control valve V-5 can be in any position. All the pumps are turned off. The 55-gallon drum is filled to the 50-gallon mark with water. It is important to review the calculation requirements before you begin the experiment. There is certain data or information that must be recorded in order for you to complete the calculations correctly.

**Pump Characteristic Curve Measurement**

1. Half of the groups measure the data for pump #1 as well as for pumps #1 and #2 operating in series. The other half of the groups measure the data for pump #2 and the data for pumps #1 and #2 operating in parallel.
2. Align flow from the 55-gallon drum through pump #1 or #2 depending on the group and back to the 55-gallon drum while bypassing the chemical process.
3. Close V-5 and start the pump(s). Record pressures and flows. This first point gives the "shutoff head" of the pump (i.e., no flow).
4. Obtain the next point at the lowest flow rate achievable with the flow meter. This is accomplished by opening V-5 approximately 1/4 turn, and then slowly closing the valve until the flow decreases to the minimum possible value. You might have to do this several times to get a feel for the response of the valve. Record pressures and flows.
5. After obtaining this minimum flow rate point, increase the flow rate in approximately 1/2 gpm increments until V-5 is fully open. Record pressures and flows. This should give you approximately 20 data points.
6. The first half of the groups perform steps 1 to 4 for pumps 1 and 2 configured in series. The second half of the groups perform steps 1 to 4 for pumps 1 and 2 configured in parallel. Make sure to record pressures and flows.

**Analysis**

1. Open Excel. Refer to the Excel lab for more information on plotting.
2. Create a trial number, flow rate, pressure in, pressure out, pressure drop, and head of the pump. Input your data in the respective column.
3. At the bottom left hand corner of your spreadsheet, click the “+” button to insert a new tab. Refer to your Excel plotting lab if you are confused. On this second tab, use the same column headings to input your data from either the series or parallel pump configuration.
4. Calculate pressure drop:

   \[ \Delta p = p_{out} - p_{in} \]

   - \( \Delta p \) = pressure drop (psi)
   - \( p_{out} \) = pressure measured leaving the pump (psi)
   - \( p_{in} \) = pressure measured going into the pump (psi)

5. Convert pressure from lb/in\(^2\) to lb/ft\(^2\) by multiplying by 144 in\(^2\)/ft\(^2\). (1 ft\(^2\) = 144 in\(^2\))
6. Using this simplified Bernoulli’s equation, calculate the head of the pump:
\[ h_p = \frac{\Delta p}{\gamma} \]

- \( h_p \) = head of the pump (ft)
- \( \Delta p \) = pressure drop (lb/ft^2)
- \( \gamma \) = specific weight (62.4 lb/ft^3)

7. Repeat head of the pump calculations for each data point on both tabs.
8. Plot pump head (ft) on the y-axis versus flow rate (gpm) on the x-axis on both tabs.

**Discussion**

Does the pump have a motor? Explain why or why not and the reason.

Analyze the trends on the plot. As flow rate increases, does pump head increase or decrease?

Does pump head increase or decrease with increasing pressure drop?
University of South Carolina
BBB Chemical Engineering Laboratory
Heat Transfer Analysis in Solids

**Introduction**

Heat transfer is relevant to all engineering disciplines, and is a fascinating part of the engineering sciences. Heat transfer phenomena play an important role in many industrial and environmental problems. As an example, consider the vital area of energy production and conversion. There is not a single application in this area that does not involve heat transfer effects in some way. In the generation of electrical power, whether through nuclear fission or fusion, the combustion of fossil fuels, or the use of geothermal energy sources, there are numerous heat transfer problems that must be solved. These problems involve conduction, convection, and radiation processes and relate to the design of systems such as boilers, condensers, and turbines. One is often confronted with the need to maximize heat transfer rates and to maintain the integrity of materials in high-temperature environments.

In this experiment, you will gather data from the conductive heating of solid shapes that are made of various materials. The solids are being heated (or cooled) in a water bath. The important variables to be considered are the shape of the solid and the physical properties (type of material and density) of the solid.

**Experimental Procedure**

In the laboratory, we have two solid shapes (cylinders and spheres) that have been fabricated from a number of different materials (e.g., copper, brass, aluminum, stainless steel, and possibly others). Each shape has been fitted with a thermocouple (electrical temperature sensor) that is located at the precise center of the shape. You should record all of the available shapes and materials in your lab notebook. You will select from among these to get sufficient data to meet your objectives. The raw data are centerline temperature versus time for a given solid shape. In addition, you should record all relevant descriptive data for the shape that is being used. Read all directions and examine the required calculations before beginning the experiment.

Each group each day in the laboratory will carry out experiments with every shape and every material. Half of the groups will do heating experiments. The other half will do cooling experiments. The TA will set the set point temperature for the water bath in the morning so that
it will be ready to go at the beginning of the laboratory period. After recording the initial temperature of each shape, the solid will be immersed in the constant-temperature bath and the transient temperature response will be recorded. **TO ENSURE THAT THE INITIAL TEMPERATURE OF THE SOLID IS CONSTANT, DO NOT TOUCH THE SURFACE OF THE SOLID BEFORE THE EXPERIMENT BEGINS.**

Step-by-step instructions are given below. Consult closely with your teaching assistant for further details.

1. Prior to the starting time, insure that the water bath is properly filled. The water should be one inch from the top and should cover the heater, pump, and one inch of the temperature sensor. Consult with your TA.
2. Prior to the starting time, turn on the water bath, controller, and potentiometer. Set the controller to the desired water bath temperature (the *set point* temperature).
   a. In order to set the controller to the desired temperature, press the Set button on the controller. Then enter the value of the set point, including all decimal places. Then press enter. The set point will then appear on the controller screen.
   b. Allow sufficient time for the water bath to stabilize completely at the set point. It may take over an hour.
   c. The spare thermocouple should be placed in the small hole next to the controller and plugged into the outlet labeled 1. Then the measured value recorded by the thermocouple and associated equipment can be compared against the controller value.
3. Turn on the computer and monitor. After Windows is loaded, double click on the icon labeled “Heat Conduction” to start the monitoring program, which is the software LabView. A window will appear which will specify the username as Unit Operations Laboratory. Click OK or press Enter.
4. **Heating the solids from room temperature to a higher temperature:** The bath temperature will be between 40 and 80°C. The TA will give the particular temperatures to your group.
5. **Cooling the solids from room temperature to a lower temperature:** The temperature goal will be between 5 and 15°C. Consult your TA on the particular temperature. The temperature range of the water bath will be from 3°C to 90°C. **Please be very careful not to burn yourself with hot**
water or the hot solids. Lift the solids using the support wire, and use gloves or tongs if needed.

5. Record the initial temperature (room temperature) of the solids in your lab notebook. Prepare to monitor the thermocouple temperature by using the mouse to click on the start or run arrow at the top of the Heat Conduction program window. It is simplest to start a new data file for each experiment. See 6 below for more details on the data acquisition software.

6. You need to store the data file name in the appropriate space on the hard drive. Be sure to use the following form when specifying the file name in the data acquisition program:

   `C:\Heat Conduction\yourfilename.txt`

   a. When you are ready to begin recording data to the file, use the mouse to toggle the “off” key by “Enable Filing”. You should not begin recording until just before the solid is placed in the bath.

   b. The computer program will record the temperature and time elapsed since the monitoring was begun. In order to determine the relative time since the beginning of the testing of the particular solid, one will need to adjust the time values.

7. **Remember: DO NOT touch the solids before you drop them into the water bath.** After the bath temperature is stabilized and the data acquisition system is ready, you may immerse the solid in the water bath. First, hook the solid to the fish-eye on the frame. Insure that you have begun recording the data. Then lower the solid into the water bath until completely submerged. Don’t drop the solid in the bath, but do try to get it immersed quickly. At the instant the solid is immersed, note the time on the data acquisition system. There may be a lag between the time shown on the data acquisition and the actual “time zero” that the solid began heating. If you touch the solid before dropping it into the bath, you will need to let that solid sit at room temperature and run it last. The reason for this is because if you touch the solid before, the solid will no longer be completely at room temperature.

8. When the solid has reached the temperature of the bath and remains stable, disable the data acquisition. Remove the solid and hang it back over the plastic tub so that it can cool to room temperature. Make sure that the data is saved on a thumb drive.

9. Repeat the items 6 through 8 for each solid.

**Analysis**

Open Excel.
Input the data (time and temperature) you obtained from the lab into your spreadsheet. Insert a chart. Under the Scatter category, choose a Marked Scatter Plot. Plot the temperature (°C) on the y-axis versus time (s) on the x-axis. Make sure to label your axes and title your plot. Make a plot for each shape and material used (i.e. one plot for the brass sphere, one plot for the aluminum cylinder, etc.). Plot the cooling and heating objects on the same graph.

**Discussion**

What trends do you observe from the objects being heated? What trends do you observe from the objects being cooled? Explain the differences between the objects. Explain the differences between the shapes.
Objective and Background

Solid slurries are frequently encountered in chemical manufacturing operations. Filtration is a physical separation process that is used to isolate the solids as a “cake” from the liquid filtrate. The plate-and-frame filter is a common unit operation. It is inherently an unsteady state operation. Plate and frame filtration is commonly used in beer production to remove excess particulates, reduce the cloudiness of the beer and sterilize the product. The objective of this experiment is to investigate the relationships between the filtrate flow rate, pressure, and filter cake thickness.

Experimental Equipment

The slurry to be filtered is CaCO3 (chalk for athletic fields) in water. The apparatus has the following main components:
1. Filter press and pump
2. Mixing tank and stirrer
3. Scale
In addition, the following items are used to determine the concentration of CaCO3 in the slurry:
4. Flask
5. Small scale for weighing

Experimental Procedure

Caution: Do not place any plate elements on the expanded metal mesh (i.e., the screen) inside the recirculation tank. The screen cannot support the additional weight. Anything that falls into the tank could potentially destroy the impeller.

Initial conditions (recirculation only)
This mode is set up at the beginning of the laboratory period, or between runs, in order to pump the slurry continuously from the tank, through the pump, back to the tank. The filter press is bypassed when in recirculation mode.

Valve positions:
- V-1 full open
- V-2, V-3, V-4 full closed
Bench Scale:
- Scale zeroed with 28 gal. plastic container on scale
Computer:
- C:\labview\scale\scale.vi file opened and student’s file entered in the file path block. Start the program by pressing Control-R.
Slurry preparation and filter paper installation (while the system is in recirculation mode)

1. Remove the pressure transducer and clean any CaCO3 from the piping.
2. Crank hand-wheel on the end of the filter press to loosen the sections of the press. Remove sections from rack.
3. Install two sheets of filter paper between each section.
4. Replace sections on rack; take care to maintain the numerical sequence for each section. Crank hand-wheel to tighten the sections into place. Use the ratchet to tighten the sections together.
5. (First group only) Add predetermined amount of chalk to the mixer – consult with lab TA for exact amount.
7. Measure the mass of the Erlenmeyer flask on the scale.
8. Dip the beaker into the mixer to capture a sample of the slurry. Pour the sample into an Erlenmeyer flask up to specified volume line on flask. Place flask on scale and measure resulting mass.
9. Subtract mass of the flask from the total mass to determine the mass of the slurry. Record this in the lab notebook.
10. Calculate the density of the slurry by dividing the mass by the volume. Make this measurement prior to each run. Tabulate the results.

Operational procedure for constant pressure runs

1. Start the apparatus with mixer and filter press in circulation mode for several minutes.
3. Open V-3 (filtrate re-circulation valve) and slowly close V-1 (slurry re-circulation valve). This will start flow through the filter press. Remain in this configuration until the pressure increases to the desired value (the Teaching Assistant will provide these values) and the filtrate returning to the mixing tank is clear.
4. Once the filtrate is clear and the pressure is 1 psi above desired, open V-4 (filtrate outlet valve), close V-3 and start the computer data logging.
5. Maintain pressure at the desired value by gradually opening V-1.
6. Run filter press until the desired data has been obtained. Stop the flow of filtrate (by opening V-3 and closing V-4) when the desired pressure cannot be maintained, the filtrate is about to overflow the container, or the scale is reaching its maximum capacity (200 lb.). Stop data logging and computer program.
7. Fully open V-1, Close V-2 and V-3. Open V-4 to drain the water from the filter press.
8. Turn off the mixer and the filter press circulation pump. Return the filtrate and chalk to the mixing tank.
9. Repeat the experiment two more times at different constant pressures (ask the TA for the conditions).
10. Clean area around filter press when experiment is completed.

Calculations
1. Using excel, plot the weight of the filtrate versus the elapsed time (Both of these were measured during the experiment by the computer)
2. Using excel, plot the pressure drop versus time (Both were recorded by computer)
3. Using the weight measurement, construct a volume versus time plot in excel
   \[ Volume = \frac{Weight}{Density} \]
4. How does increasing pressure effect the rate at which the weight increases? Decreasing pressure?
5. How would increasing density of the liquid effect the volume that was calculated?

**FIGURE 1**
FILTRATION EQUIPMENT FLOWSHEET
Introduction:

One of the most important of all mass-transfer operations is distillation, which is also referred to as fractionation or fractional distillation. Distillation is the most important and widely used method of industrial separation because it can separate a feed stream into pure products that require no further processing. Distillation is the most basic form of chemical separation because it relies solely on a large difference in boiling points between different chemicals. Some examples of distillation include pure oxygen from air and gasoline, kerosene and fuel oils from crude oil. The major issue with distillation is that in some cases the composition of the liquid phase is very similar to that of the vapor phase, thus very little separation has occurred. In this case, it is necessary to have many equilibrium stages in a distillation column.

In large scale distillation operations such as oil refineries, plants run 24 hours a day on a continuous distillation basis. Batch distillation, on the other hand, is used in smaller laboratories and small scale production units. This batch distillation is often used to make highly pure chemicals on an “as needed” basis.

Distillation is commonly used in the production of alcohol. The fermented mixture of water and alcohol is placed in a copper still pot and allowed to boil to the alcohol’s boiling point. Since alcohol is more volatile than water, it will boil off into the vapor phase first leaving behind the waste water. This vapor can then be condensed in an additional column and collected as purified alcohol (typically 60-80%). Traditional distilleries use a batch distillation process but modern technology has allowed for continuous distillation through many interconnected pot stills.

Objective:

The purpose of this study is to evaluate the performance of a batch distillation under specified reflux rates. The column will be separating ethyl alcohol and water. The process variables are feed composition (initial feed of materials), heating rate and reflux ratio. For the purpose of this study, only the reflux rate will be varied.

Background:

Distillation is a chemical engineering operation in which 2 phases (liquid and vapor) are present through evaporation and condensation. Distillation simply involved the boiling of a feed solution to produce 2 or more separate products. The separation and purity of the feed components into final products is solely driven by the difference in boiling points of the chemicals. The more volatile component (lower boiling point) will be present in a larger concentration in the vapor phase, whereas the less volatile component will be more present in the liquid phase. The highest temperatures can be found at the bottom of the column and the lowest at the top as the liquids and vapors are each at their respective bubble and dew point temperatures.

In batch distillation, the feed stock is added one time to the column and removed at the end from the still as pure product. Nothing is removed from the still pot until the full distillation has been completed.
**Terminology:**

Some of the terminology describing batch distillation is presented below, along with suggested units for this procedure. The various streams are described in units of volume for this procedure because volume is conveniently measured using graduated cylinders. Recall that mass not volume is conserved.

**Still contents, or residue (W, mL):** W is the amount of liquid (residue) left in the still pot. The initial charge to the still pot is $W_0$. The composition of the still pot is $x_m$.

**Overhead vapor rate (V1, mL/hr):** The rate at which vapor leaves the top tray (n=1) in the column. Although $V_1$ is a vapor stream, one could report its flow rate as mL/hr of the equivalent condensed liquid (as if the $V_1$ had been captured and condensed to a liquid).

**Distillate (or Product) Rate (D, mL/hr):** The rate of liquid distillate removal, which is enriched with the light key. The composition of the distillate is $y_d$, which, for a binary system, completely describes the composition. The total amount of distillate collected may also be given the symbol D.

**Reflux Rate ($L_0$, mL/hr):** The rate of liquid condensate returned from the condenser to the top tray of the column. Note that if all flows are reported as condensed liquid and if the densities of all streams are approx. equal, then $V_1 = L_0 + D$.

**Reflux Ratio (R):** The reflux rate ($L_0$) divided by the distillate rate (D). Note that $R/(R+1) = L_0/V_1$ or $R = L_0/D$.

**Equipment:**

1. Ethyl alcohol ($C_2H_5OH$ or EtOH) *take note of the concentration*
2. Deionized (DI) Water
3. Cooler filled with ice (to keep condensate and samples chilled)
4. Oldershaw column
5. Two type K thermocouples hand-held readings
6. Heating mantle
7. Variac power supply
8. Recirculating chiller
9. Pump, used to recirculate and mix the still pot contents and force the still pot contents through the sampling system
10. Sample vials with caps and labels
11. Paar DMA-48 digital density meter with ethanol/water calibration curve (used to analyze the composition of samples)

**Experimental Procedure:**

The batch distillation experiment takes several hours to heat up and stabilize at the chosen reflux ratio before one can actually begin fractionation and samplings. Therefore, one student and the TA must go to the lab in the morning to start up the system. Each group will be preforming one batch distillation.

1. While the column is operating at the given reflux ratio, record the temperature several times to assure that it is not changing (steady state).
2. If necessary, recalibrate the densitometer using the given instruction guide. Sample a pure water reference and verify that the density is correctly reported on the densitometer as compared to the reference standard.
3. Sample the still pot residue according to the instructions given to you by the TA. Activate the required method on the densitometer “density”. Ensure that the measurement cell is completely dry. Place the sample in question inside the chamber and allow the densitometer to collect its readings. **Be sure that the pump has been recirculating the still pot for at least 5 minutes and remains on throughout the experiment.**

4. When you are ready, start withdrawing distillate from the system continuously. Mark this as the time zero in the batch distillation process. (You should verify that the reflux ratio is correct by determining the percent of time that the distillate is withdrawn.)

5. Take process readings every five (5) minutes, which include the still pot and overhead vapor temperatures and the cumulative distillate volume.

6. Sample the still pot and distillate every ten (10) minutes by filling and labeling the small vials provided.

7. Use the densitometer and the calibration curve to determine the composition of the distillate and bottoms samples. Run DI water and pure ethanol as standards every fifth sample to ensure that the densitometer is stable. See step 3 for further densitometer instructions.

Calculations:

1. Using excel, plot the distillate volume versus time (both recorded in the lab notebook).
2. Determine the distillate flow rate (D) as a function of time and plot (volume/time vs time).
3. Determine the overhead vapor rate (V₁) as a function of time using the equation below and the given reflux ratio:

   \[ R = \frac{L₀}{D} \]

   \[ V₁ = L₀ + D \]

4. Determine the reflux rate (L₀) as a function of time.

5. Plot the still pot and overhead temperatures versus time.

6. Plot the alcohol concentrations in the still pot and in the distillate versus time.

7. What is the driving force for distillation?

8. What would happen if the column was run in total reflux mode?
Figure 1. Schematic of continuous-feed distillation column
Figure 2. Batch distillation with fractionation and reflux.
University of South Carolina
BBB Chemical Engineering Laboratory
Ethanol Fermentation with Sugar and Yeast

Introduction:

One of the most influential chemical reactions throughout history has been the fermentation reaction. Fermentation in beverages has been documented dating back to 6600 BCE in China but the discovery of yeast and bacteria did not occur until much later. Yeast was discovered by three independent publications around 1837 by microscopic investigation. Bacteria was soon also discovered but was not called bacteria until the 1870s. These investigations were completed due to the fact that wine, beer, and bread were the main foods in Europe at the time. In the 1850s, Louis Pasteur used a series of investigations to show fermentation is caused by living organisms. Pasteur correctly concluded that certain types of microorganisms cause specific types of fermentation and end-products.

Ethanol fermentation is used in the production of ethanol for food, alcoholic beverages, and the fuel energy. Alcoholic fermentation is a process that is considered an anaerobic process. This means that yeast performs the conversion in the absence of oxygen. Large scale fermentation processes are conducted in wineries and breweries across the world. Large scale bread processes also utilize fermentation reactions.

Objective:

The purpose of this study is to evaluate the production of ethanol from a sugar and water mixture under specified conditions. The process variables are temperature, yeast to sugar ratio, and mixing rate. For the purpose of this study, only yeast to sugar ratio will be varied.

Background:

Fermentation is a chemical reaction involving a microorganism consuming sugar and releasing carbon dioxide and an alcohol. These microorganisms range from different types of yeast to bacteria. The most well-known fermentation reaction is alcoholic fermentation where yeast is used to produce ethanol and carbon dioxide. This reaction is utilized in the alcoholic beverage and food industry. In the alcoholic beverage industry, large amounts of water, sugar, and yeast are added to a vessel. The reaction then takes place for an extended period of time. The products are then filtered and depending upon the final product, distilled or bottled. In the bread making process, yeast reacts with the sugars in the bread. The ethanol evaporates and the carbon dioxide causes the bread to rise.
**Equipment:**

1. Water
2. Sugar (sucrose)
3. Yeast
4. Paar DMA-48 digital density meter (used to analyze composition of samples)
5. Side-arm flask (vacuum filter)
6. Filter paper
7. Büchner funnel
8. Aeration and Agitation lab apparatus
9. Recirculating heating bath

**Experimental Procedure:**

The fermentation experiment requires several days for the reaction to reach noticeable levels of ethanol. One group will start the lab and each successive day the groups will take a measurement. These measurements will be used to do the calculations section.

1. To begin experiment, fill vessel with 20 liters of water and add 900 grams of sucrose sugar. Turn on motor to mix this solution and ensure it is well mixed. Next, take a sample from the bottom outlet. Measure the density of this sample in the DMA-48 densitometer. Record measurement.
2. Turn on recirculating heating bath, and raise temperature of solution to 25°C.
3. Measure and add yeast depending on specified yeast to sugar ratio (TA will provide).
4. Close vessel and turn propeller RPM to 400 to ensure complete mixing but no effect on temperature.
5. Allow to run overnight and throughout all days of lab.
6. Each day a different group (other than the first group) should take a measurement from the bottom outlet tube of the vessel.
7. The measurements will have to be filtered using a side-arm flask, Büchner funnel, and filter paper. The filter paper will be supplied and the side-arm flask must be connected to a vacuum. The sample will be poured onto the filter paper in the funnel and the liquid components will pass through the filter paper. The solution should lose its yellow coloring after passing though the filter. Be sure to not turn the vacuum too high as it can suck samples into the tube and tear the filter paper.
8. Take the filtered solution and measure the density using the DMA-48 densitometer. Record measurement.
9. The last group of the week will drain entire vessel and dispose of contents accordingly. Then fill the vessel with water to clean it and then drain and dispose of water.
Calculations:

Density of ethanol is 0.79 g/mol = \( \rho_E \)

Molecular weight of ethanol is 46.07 g/mol = \( MW_E \)

Molecular weight of mixture is 18.76 g/mol = \( MW_M \)

1. Water and sugar mixture density: ________________ g/mol = \( \rho_M \)

2. Sample density: ________________ g/mol = \( \rho \)

3. Determine mole fraction of each component in sample

\[ X_E = \frac{\rho - \rho_M}{\rho_E - \rho_M} \]  
(1)

\[ X_M = 1 - X_E \]  
(2)

\[ X_E = \text{______________} \quad X_M = \text{______________} \]

4. Assuming a one mole basis, determine the volume percentage of ethanol

\[ X_E \cdot MW_E \cdot \frac{1}{\rho_E} = V_E \quad \text{Volume of ethanol in mL} \]  
(3)

\[ X_M \cdot MW_M \cdot \frac{1}{\rho_M} = V_M \quad \text{Volume of mixture in mL} \]  
(4)

\[ \text{Volume % of ethanol} = \frac{V_E}{V_E + V_M} \times 100 \]  
(5)

Volume % = ________________

5. Solve for proof of the alcohol by multiplying the volume % by two

Proof = ________________

6. What would be the density of a solution that is 50 proof? Assume everything holds constant except for volume of ethanol.
Optional In-Class Activities

Separation of Cereal

**Description:** Have a variety of different cereals in a ziplock bag all mixed together. The students are tasked with separating out the different types of cereals using a variety of separation techniques. They will be provided a Styrofoam bowl, an additional bag, a piece of paper, tape and whatever other supplies may be on hand. This is a visual example of separation of various compounds.

**Outcomes:** A visual representation of separation of various chemicals. Students gain an appreciation for why different separation techniques are needed for different chemicals and begin to think critically in response to open ended questions.

Engineering Ethics Case Discussion

**Description:** Students will be given an example engineering disaster problem presentation. This will include background, circumstances of the disaster, history, and all sides of the issue including preventative measures for the future and lessons learned. Students will then be assigned a disaster of their own to research in groups. They will need to look up what occurred in the disaster and its causes and effects. Student will then present their findings to the class and open the floor for discussion on how something like this can be prevented in the future.

**Outcomes:** Students will be introduced to notable engineering disasters in order to learn that these things are entirely possible. Students will also have the opportunity to critically think about what can be done in the future to prevent these types of disasters. Students will understand all the behind the scenes of a large engineering feat and how a tiny mistake can be costly.

VLE Distillation Demonstration

**Description:** AICHE has a 1-minute demonstration video showing how molecules move from the liquid to the vapor phase. [https://www.aiche.org/academy/videos/vapor-liquid-equilibrium-ratio-demonstration](https://www.aiche.org/academy/videos/vapor-liquid-equilibrium-ratio-demonstration) Show this video after explaining the basics of VLE. Next, display a bowl of
red and blue M&Ms. Try to move as many red M&Ms as possible into the next bowl while picking up at least 4 M&Ms in a hand at a time. Students will find it hard to just move the red M&Ms and will have some blue in the other bowl along with the red. This will display how difficult it is to achieve separation with molecules of the same size.

**Outcomes:** Students can visually see how difficult it is to achieve separation in VLE and isolate one molecule in a single phase. There will always be some of the other components in each phase.

Fermentation in a Bag:

**Description:** [https://www.glbrc.org/education/classroom-materials/fermentation-bag](https://www.glbrc.org/education/classroom-materials/fermentation-bag)

Students are given room temperature water, sugar, and basic baker’s yeast. These will all be mixed in different quantities and placed into plastic ziplock bags. These bags will then be drained of air and sealed. Allow the bags to sit for the duration of the class, or overnight if needed. After some time has passed, students can observe the bags beginning to inflate. That is the CO2 being produced. Further activities, students can measure the bag inflation height in order to determine which combination was most successful or use a breathalyzer to test alcohol content in the bag.

**Outcomes:** This activity will give students a visual demonstration of how fermentation works. They will be able to observe how CO2 is produced over time, thus inflating the bag. They can also determine which combination of yeast, sugar and water was most effective for the fermentation. Students should note that there is a maximum amount of sugar water that the yeast can handle before effeteness decreases.

Comparing Biofuels to Fossil Fuels:


The instructor will set up this experiment prior to class, with one cotton ball soaked in vegetable oil and the other in motor oil. The instructor will set up the apparatus as seen in the
The cotton balls will be ignited and the time of burning will be recorded. Similarly, the temperature of the water in the aluminum can will be recorded prior to and after the burning to observe the temperature difference. This can be correlated to the amount of energy transferred by each fuel source.

**Outcomes:** Students will be able to observe and quantify the energy of each fuel source. The time alone will show which is more effective. However, measuring temperature change will also give a great indication of which fuel source can produce more energy as the heat is transferred from the fire to the liquid. Students will have a greater appreciation for which energy sources give the most energy as well as how much of a biofuel is needed in order to be comparable to the traditional fossil fuels.

**Build a Brewery**

**Description:** Students will be given a list of components that make up a brewery (or any basic chemical engineering process). They must correctly place them in order from reactor feed preparation all the way to recycle structure. This list will include the likes of pumps, compressors, heat exchangers, plate and frame filtration, reactors and vessels. Students will then stand in front of the class and discuss each of their plants and how the product flows through it.

**Outcomes:** This is a summation of the topics from the whole semester. Through this activity students will test their knowledge of the different sections of a chemical plant while also recalling all the various unit processes. This will give students a taste of what it is like to develop a plant, much like the senior capstone project for Chemical Engineers but on a small scale big picture level.

**Keirsey Temperament Sorter**

**Description:** For homework, have the students take the Keirsey Temperament Sorter Personality Assessment. When they get to class, have them sort themselves into the 4 temperaments: Guardians, Artisans, Idealists, and Rationals. Assign groups based on temperaments, ideally having one of each type of personality in a group. Once the groups are
assigned, give each group a pack of balloons and tape. Have the groups build the tallest free
standing balloon tower they can in 10 minutes.

**Homework:** Take the Keirsey Temperament Sorter Personality Assessment on keirsey.com.
Write down the results and bring them to class.

**Outcomes:** Learn your own personality type and observe what it is like to work with people
who have different personalities. Use your own creativity to build the tallest balloon tower.

### 14 NAE Grand Challenges for Engineering

**Description:** Have each student/group explore one of the 14 Grand Challenged for Engineering.
Have the student/group present the challenge to the class and discuss as a class potential
solutions that are being worked on to solve that challenge.

**Homework:** Visit the NAE Grand Challenges for Engineering website:
[http://www.engineeringchallenges.org/](http://www.engineeringchallenges.org/). In class the following day, have students/groups sign
up for the challenge they would like to present. Try to only have one for each challenge. Assign
each student/group to create a presentation for 3-5 minutes on their challenge.

**Outcomes:** Enlightens students to the big challenges that engineers are currently facing. Engage
in a discussion on the challenges to bring an interdisciplinary perspective on the topics.

### Heat Transfer using Pancakes

**Description:** Bring a griddle to class and make pancakes to demonstrate the different types of
heat transfer (conduction, convection, and radiation).

**Outcomes:** Use a real life visual to demonstrate complex concepts in chemical engineering.

### Peanut Butter and Jelly Lab Procedure

**Description:** Students will be asked to develop a procedure that could be used to make a
peanut butter and jelly sandwich. This will include objectives, individual steps, and equipment
needed. The professor will then choose one of the procedures and follow it explicitly one day in
class.
Outcomes: Students will be introduced to the process of writing laboratory procedures. This will give students practice writing a detailed procedure and help them see how explicit instructions need to be. Ideally the professor will choose a procedure that is not detailed enough, allowing students to visually learn how much detail is needed.
Introduction to Chemical Engineering for Non-Majors
Honors Thesis Defense
Kelly Kopchak, Jacob Lambert, Kayla Revelle
Ed Gatzke

Outline
- Introduction to Thesis Project
- Syllabus
- Lecture
- Labs
- In-Class Activities
- Conclusion

Objective
- Create a new SCHC lab science curriculum
  - Goal: course to be approved and offered by Spring 2018
- Prepare course materials:
  - Syllabus
  - Textbook
  - Lecture presentations
  - Laboratory materials
- Introduce non-technical students to engineering principles

Personal Motivation
- Dispel myths surrounding chemical engineering
- Motivate students to explore new topic areas
- Create a fun, exciting course
- Educate students on the every day impact of engineers
- Give back to the next generation of SCHC students

What is Beer, Booze, and Biofuels?
- Introductory chemical engineering course
  - Targeting Honors students outside of CEC
  - Laboratory component
  - Focus on the basic ECHE courses
- Honors aspects:
  - Dynamic lectures
  - Beyond the classroom experiences
  - Engaging in-class activities
  - Stimulating laboratory experiments

Approach and Methodology
- Revisited previous coursework
  - Prioritized the most important basic topics
  - Consolidated into rudimentary lessons
- Developed a concise reference textbook
- Created relevant lecture presentations
- Adapted laboratory experiment procedures
Syllabus
Prepared by Dr. Ed Gatzke

Course Description
Beer, Booze, and Biofuels. (3) (Prereq: none) A qualitative introduction to fundamental scientific and engineering principles commonly applied in the chemical process industries. Specific applications considered include reactive, separation, and energy systems in the context of production of brewed products, distilled spirits, and liquid fuels. (Specifically designed for non-science and non-engineering majors.)

Course Goals
1. Students will demonstrate understanding of the basic components of a chemical process
2. Students will remember basic facts related to fermentation, separation, and energy processes
3. Students will demonstrate the ability to convert basic unit measurements
4. Students will demonstrate a basic ability to analyze data from a chemical process

Course Objectives
Students should develop a conceptual understanding of chemical process systems and how chemical process technologies relate to society. Course topics include fermentation reactions, distillation separations, and energy production.

Specific Course Topics
- Converting units
- Chemical reactions
- Types of beers and wines
- Types of distilled spirits
- Basics of fermentation reactions
- The brewing process
- Force, energy, work, and power
- The general mass balance equation
- Types of energy

- Yield, specificity, and selectivity
- Chemical process unit operations
- Introductory concepts from transport phenomena
- Basics of vapor-liquid equilibrium
- Measuring experimental values
- Density, concentration, and ideal gas
- Excel plotting and analysis

Course Laboratory Experiences
1. Introduction to Excel using formulas and cell referencing
2. Plotting data in Excel
3. Pumps experiment
4. Heat conduction and convection experiment
5. Filtration experiment
6. Distillation experiment
7. Fermentation experiment
8. Brewery tour
9. Distillery tour
10. Biofuels process tour
Course Textbook

- Prepared by Kelly Kopchak
- In depth discussion of course topics
- Breaks topics into 15 overarching lessons
- Reference book to supplement lectures and labs

Course Presentations

- Prepared by Jacob Lambert and Kayla Revelle
- Adapted from textbook material
- Lectures prepared for each course topic
- Total of 18 presentations made

Unit Operations and Conversions

A Milli- A Milli- A Milli-

Beer, Booze, and Biofuels

Chemical Engineering for Non-Majors

Ed Gatzke
Kelly Kopchak, Jacob Lambert, Kayla Revelle

Who is this?

A Isaac Newton (1642-1726)
B Joseph Gay-Lussac (1778-1850)
C Amedo Avogadro (1776-1856)
D Lord Kelvin (1824-1907)
E I have no clue and don’t care

D Lord Kelvin (1824-1907)

He is known for determining the correct value of absolute zero

Why Do We Need Units?

- The mass of this object is 2
- 2 what?????
- Units give values relative to other objects in our universe

The other group of measurements was included to ensure that the English system is maintained. From the US, Canada, India, and Pakistan, the English system is a customary unit of measurement. This includes length, area, and temperature. It is used in the states where this system is used. For example, the size of something is described in a list, instead of units. These have units:

- Length
- Mass
- Time
- Temperature

The base units are as follows:

- Meter
- Kilogram
- Second
- Kelvin

The standard units are as follows:

- Inch
- Pound
- Second
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He is known for determining the correct value of absolute zero
Definitions

• **Base Unit** - base quantity used as the standard for a specific measurement and cannot be broken down into further units
  - Mass: matter in an object
  - Length: distance from end to end of an object
  - Time: the period between two events
  - Temperature: how hot or cold an object is

• **Systems of Measurement**:
  - International System (SI) or Metric
  - English

### SI Units

<table>
<thead>
<tr>
<th>Base Quantity</th>
<th>Common Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>meter (m)</td>
</tr>
<tr>
<td>Mass</td>
<td>kilogram (kg)</td>
</tr>
<tr>
<td>Time</td>
<td>second (s)</td>
</tr>
<tr>
<td>Temperature</td>
<td>Celsius (°C)</td>
</tr>
</tbody>
</table>

### SI Prefixes

<table>
<thead>
<tr>
<th>Prefix</th>
<th>Conversion Factors</th>
<th>Prefix Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>milli-</td>
<td>10⁻³</td>
<td>m</td>
</tr>
<tr>
<td>centi-</td>
<td>10⁻²</td>
<td>c</td>
</tr>
<tr>
<td>deci-</td>
<td>10⁻¹</td>
<td>d</td>
</tr>
<tr>
<td>base</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>deca-</td>
<td>10²</td>
<td>da</td>
</tr>
<tr>
<td>hecto-</td>
<td>10³</td>
<td>h</td>
</tr>
<tr>
<td>kilo-</td>
<td>10⁶</td>
<td>k</td>
</tr>
</tbody>
</table>

- The SI system is based on units of 10
- You can change units by using the conversion factors
- **Examples**:
  - \(5 \text{ m} \times \frac{1 \text{ cm}}{10^{-2} \text{ m}} = 500 \text{ cm}\)
  - \(0.0032 \text{ kg} \times \frac{10^3 \text{ g}}{1 \text{ kg}} \times \frac{1 \text{ mg}}{10^{-3} \text{ g}} = 3.2 \text{ mg}\)

### English Units

<table>
<thead>
<tr>
<th>Base Quantity</th>
<th>Common Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>foot (ft)</td>
</tr>
<tr>
<td>Mass</td>
<td>pound (lb)</td>
</tr>
<tr>
<td>Time</td>
<td>second (s)</td>
</tr>
<tr>
<td>Temperature</td>
<td>Fahrenheit (°F)</td>
</tr>
</tbody>
</table>

### Time Conversions

- SI and English systems use the same units and conversions for time:
  - 60 seconds (s) = 1 minute (min)
  - 60 min = 1 hour (hr)
  - 24 hr = 1 day
  - 7 days = 1 week (wk)
  - 365 days = 1 year (yr)
  - 52 wks = 1 yr

**Example**:

\[
2 \text{ yrs} \times \frac{365 \text{ days}}{1 \text{ yr}} \times \frac{24 \text{ hr}}{1 \text{ day}} \times \frac{60 \text{ min}}{1 \text{ hr}}
\]

\[
= 1,051,200 \text{ min}
\]
Converting Between SI and English Units

<table>
<thead>
<tr>
<th>SI Unit</th>
<th>English Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.54 cm</td>
<td>1 in</td>
</tr>
<tr>
<td>1 m</td>
<td>3.2808 ft</td>
</tr>
<tr>
<td>454 g</td>
<td>1 lb</td>
</tr>
</tbody>
</table>

Examples:
- \(57 \text{ in} \times \frac{2.54 \text{ cm}}{1 \text{ in}} = 145 \text{ cm}\)
- \(3928 \text{ g} \times \frac{1 \text{ lb}}{454 \text{ g}} = 8.652 \text{ lb}\)

Absolute Temperature

- Celsius and Fahrenheit are the most common temperature scales used on a daily basis.
- Kelvin and Rankine are absolute temperature scales meaning that the coldest physical temperature occurs at zero.

<table>
<thead>
<tr>
<th>Scale</th>
<th>Boiling Point</th>
<th>Freezing Point</th>
<th>Absolute Zero</th>
</tr>
</thead>
<tbody>
<tr>
<td>Celsius</td>
<td>100</td>
<td>0</td>
<td>-273</td>
</tr>
<tr>
<td>Fahrenheit</td>
<td>212</td>
<td>32</td>
<td>-460</td>
</tr>
<tr>
<td>Kelvin</td>
<td>373</td>
<td>273</td>
<td>0</td>
</tr>
<tr>
<td>Rankine</td>
<td>672</td>
<td>492</td>
<td>0</td>
</tr>
</tbody>
</table>

Temperature Conversions

- Celsius (°C) to Fahrenheit (°F): \(°F = \frac{9}{5} \times °C + 32\)
- Fahrenheit (°F) to Celsius (°C): \(°C = \frac{5}{9} \times (°F - 32)\)
- Celsius (°C) to Kelvin (K): \(K = °C + 273\)
- Fahrenheit (°F) to Rankine (R): \(R = °F + 460\)

Temperature Examples

- Fahrenheit to Celsius:
  \[
  \frac{5}{9} \times (75 \text{ °F} - 32) = 24 \text{ °C}
  \]

- Celsius to Kelvin:
  \[
  24 \text{ °C} + 273 = 297 \text{ K}
  \]

- Kelvin to Rankine:
  \[
  \frac{5}{9} \times 277 \text{ °C} + 32 = 530.6 \text{ °F}
  \]

Laboratory Experiments

- Prepared by Kelly, Jacob, and Kayla
- 7 in lab experiments and 3 tours
- Lab safety day included
- Adapted from ECHE Unit Operations lab procedures
- Focused on principles of measurement and observation
- Analysis focused on mastery of Excel and plotting graphs
In-Class Activities

• Per SCHC guidelines, courses should include additional engagement opportunities
  • Fosters teamwork and critical thinking skills
• Optional activities include:
  • Keirsey Temperament Sorter
  • 14 NAE Grand Challenges for Engineering
  • Heat Transfer with Pancakes
  • Peanut Butter and Jelly Lab Procedure
  • Separation of Cereal
  • Build a Brewery
  • Engineering Ethics discussion

Conclusions

• Course material was developed for an introductory chemical engineering course for SCHC
  • Syllabus, textbook, lectures, labs
• Wide variety of topics covered
  • Chemistry, thermodynamics, energy, conversions, alcohol
• Initial steps taken to offer the course in Spring 2018
  • Next steps?