Standing Instructions for Students (SIS)
CH402 Chemical Engineering Process Design, AY2024-2025

CONTACT INFORMATION

Instructor: Dr. Biaglow
Office: BH441
Phone: x4080
Classroom: BH331 (computer lab)
Hours: B1-Hour, 0845-0940, T2-hour 1245-1445
D1-Hour, 1055-1150, S2-hour 1245-1445

COURSE INTRODUCTION AND OVERVIEW

You have been studying chemical engineering for about two years. At this point, you should understand that learning to solve complex problems is paramount, but developing the necessary skills and experience is highly circular. That is, you need a certain amount of experience to solve engineering problems, but you cannot get that experience without solving problems. The more problems you solve with your instructor and your classmates, the more experience you develop, and the better you will become at solving problems. This is the primary emphasis of the chemical engineering program at USMA, but the same can be said of other programs.

How does a chemical engineer differ from other engineers? I have already said that all engineers solve problems. Chemical engineers solve problems involving chemical composition. For example, a typical process might start with raw materials, but the raw materials might contain little or none of the desired substance. A good example is uranium ore, which contains $UO_2$ and must be converted to *metallic* uranium to be useful. The raw material (uranium ore) undergoes a series of processing steps involving chemical and physical changes, the result of which is a new material having a different chemical composition (metallic uranium). Another example is the conversion of crude oil into gasoline. Crude oil is a complex mixture of hydrocarbons, water, and various minerals. The water and minerals in the crude oil are washed and decanted out, and the remaining hydrocarbons are distilled, cracked, and alkylated until just the right mix of molecules is obtained. Numerous products come out of the refinery, to be used as fuels or as feedstock for various petrochemical processes. Both processes are highly optimized and highly controlled.

Chemical engineers design the overall processes by which the conversion steps are achieved. They also design (or develop specifications for) the individual pieces of equipment used in the process. The control and safe operation of the equipment and processes are also especially important. Chemical engineers design automatic control systems and develop operational protocols for the process. The economics of the overall process are also important, so chemical engineers optimize the manufacturing processes to minimize costs and maximize profits within constraints imposed by the end application as well as safety and environmental concerns. So, given a set of constraints (specs, control, safety, environment, economics, etc.), *the chemical engineer designs a process that meets the constraints*. In addition, once the plant or process is built and becomes operational, plant chemical engineers are vital for the troubleshooting and debottlenecking that keep the process running smoothly and efficiently after it is built.

Chemical engineers are concerned primarily with processes and equipment that cause changes in chemical composition. You are already familiar with a good deal of this technology. If someone were to ask you to design a distillation column to separate two alcohols, you already have an idea of what to do. You have learned how to determine the number of trays and feed location for the tower. You might also be able to determine if some other type of separation process would be more suitable. Likewise, you also know how to design a reactor to convert one molecule to another. As long as you know the kinetics of the reactions and flow rates of the fluids, you can determine the volume for a CSTR, PFR, or batch reactor. In this course, you will go a little further and learn how the physical design of a column or reactor determines the cost of the equipment. The equipment cost, as well as the relative value of the products and reactants, allows us to determine an economic figure of merit to evaluate the overall process.

Most of the equipment that you will encounter is “off-the-shelf.” That is, the theory and the mechanical designs have already been worked out. Your job as a chemical engineer is to determine the specifications so that a vendor can provide an exact price quote. For example, in the distillation problem, let’s say you have determined the number of trays and the feed location. In order to produce a quote, a vendor would need to know such things as column thickness and material, as well as tray properties like diameter, thickness, hole pattern, and tray material. These things then allow the vendor to determine the cost and produce a quote. Usually this is straightforward enough but requires care and can be time-consuming. Of course, in the real world, things get complicated very quickly. Sometimes, a new process or piece of equipment needs to be developed, and this usually requires a great deal of experience. A great deal of commercial equipment is proprietary which requires model development and programming that weren’t taught in class. These things may even require a research program depending on the state of the existing models.

What can you expect when you take your first job as an engineer? Fortunately, as a freshly-minted engineer, you can expect to find considerable support within your organization. Design groups in commercial companies are organized into teams whose members are chosen to provide a variety of experience levels and different points of view. This provides you with the mentorship you need to develop into a fully seasoned engineer. You will rarely be working alone. Most often, however, especially at the entry or “Bachelor of Science” level, designs involving commercial, off-the-shelf equipment are common. In these situations, your job is to determine the correct specifications for the process or equipment. As you develop experience in this area, you will find that all design projects involve considerable creativity, and that this is perhaps the most satisfying of the different jobs that an engineer does.

The commercial equipment that is commonly used in chemical processing has been broadly classified into what we call "unit operations." You may have heard this phrase in your other courses. Unit operations involved separators as well as agitators, crushes, conveyors, and the like. The term “unit processes” is an older term that describes a step in the manufacturing process that involves a chemical reaction. In either case, these units operations or unit processes have been arranged into “catalogs” that allows one to select appropriate equipment for your application. For example, gas-stripping is a unit operation. That is, all gas strippers, even though they may be quite different in detail, can be described using the same theoretical models. Alkylation is an example of a unit process. Again, the basic layout of the process is generally known, but as a designer, you will need to work out the details for your specific application. Of course, as your level of understanding improves, these basic designs change over time and innovative technology is constantly being developed. To be a successful engineer, it is important to stay abreast of all of the latest developments in your field of expertise. Just like a good kitchen designer, you need to know all the latest features and gadgets to make the kitchen work better.

*This course is concerned with the design, economics, and integration of unit operations and processes.*

While many types of engineers are able to design processes and equipment, certain key unit operations can *only* be designed by chemical engineers. This type of equipment actually produces the changes in chemical composition mentioned above. Other types of units, such as heat exchangers, pipes and valves, pumps, and compressors, etc., are considered "auxiliary" operations in the chemical plant and can be designed by mechanical engineers as well. However, in some cases, the auxiliary equipment is remarkably similar to that used for the key operations. As an example, consider agitators. Agitators are basically big blenders and are primarily *mechanical* in that the major features are the motor, impeller, and baffles. However, agitators are also commonly used in mass contactor and CSTR design. As another example, heat exchangers are similar to PFRs. Therefore, the physical design of a PFR is almost identical to the design of a heat exchanger. As yet another example, pneumatic conveyors are nearly identical to fluidized bed reactors. In many cases, the auxiliary operations are nearly identical to the key operations. For these reasons we will spend some time on auxiliary equipment to give you the tools necessary to perform a "complete" process design.

So, when designing a process, how do you begin? The process goes something like this: **First**, reactants and products are identified. That is, what will be converted, and what will it be converted to? **Second**, the properties of the reactant and product streams are determined as completely as possible. Are they gas, liquid, or solid, or a combination of two or more phases? If liquid, what are the viscosities and other relevant properties? Are the boiling and melting points known? What are the critical points and critical constants? What is the surface tension? What are the flow rates? You already know from last semester that the flow rate determines the Reynolds number, which then determines the heat and mass transfer coefficients. **Third**, determine which general operational steps are required to achieve a transition from feed to product. You will use this information to assign the specific unit operations to the process. **Fourth**, after the specific unit operations and steps are worked out, perform the mass and energy balances for each unit in the process. The balance equations are also used to design the separation systems that are used to prepare or pre-treat the feed streams, and to fine-tune the purity and overall quality of the products in any post-processing operations. **Fifth**, each piece of equipment in the process is designed according to well-defined correlations, subject to the constraints of the mass and energy balances. At any point along the way, the process can be optimized according to any number of metrics. **Sixth** and finally, the “piping and instrumentation diagram” or “P&ID” is developed from the design information. The P&ID is the exact schematic of all equipment in the final design. The process is iterative. As you acquire new knowledge and experience about the process, you may have to go back to an earlier step and repeat the process to incorporate the new knowledge.

CH402 Chemical Engineering Process Design is where we put all of the pieces of your curriculum together. In this class, you will learn how to assemble chemical engineering units (pipes, heat exchangers, reactors, and separators) into working process designs. Of course, a process is not much use unless it is economically viable. We will learn how to assess the process using economic indicators. This means that we will learn how to determine the price of each piece of equipment in the process. We will also learn how to convert fixed capital and reactant and product flows into cash flow, so that economic decisions can be made on a time-basis. You will learn how the unit operations are connected into networks (flow sheets) to accomplish a task. We then look in some detail into the economics of the process to determine the cost. Finally, we look at communication of results with the development of a design report. To this end, we shall be working towards the following course objectives:

COURSE OBJECTIVES

1. Understand the development, synthesis, and use of chemical engineering processes.
2. Understand and be able to assess the economic potential of a chemical engineering process.
3. Understand the mechanical design of auxiliary chemical engineering equipment.
4. Use and understand chemical engineering process simulators.
5. Write efficient and professional chemical engineering design reports.
6. Understand and be able to assess the various safety and environmental concerns encountered in the chemical process industry.

To achieve the course objectives, we have developed the following organizational blocks of lesson materials (a detailed lesson schedule is linked to the course web site):

COURSE LESSON BLOCK STRUCTURE

Transport and handling of fluids

Pumps, compressors, and expanders, agitators, flow measurement and storage of fluids, piping design.

Heat Exchanger Design

General heat exchanger theory, heat exchanger types and costs, heat exchanger design with and without CHEMCAD, optimum heat exchanger design.

Engineering Economics

I/O diagrams, block diagrams, functions diagrams, process flow diagrams, P&ID.

Cost estimation, capital investments, production cost and cash flow patterns, interest, discount factors, taxes and fixed charges, profitability, alternative investments.

Capstone Design Project

To assess your learning of the course objectives, we will be using the following graded events in this course:

GRADED EVENTS

| | | |
|---|---|---|
| 29 Homework Problems @ 6 pts. each: | 174 | 10.27% |
| 4 Small Design Projects @ 50 pts. each: | 200 | 11.80% |
| 2 Written Partial Reviews @ 200 pts. each: | 400 | 23.60% |
| 1 Written Design Report @ 400 pts: | 400 | 23.60% |
| 2 In-Progress Reviews @ 50 pts each: | 100 | 5.90% |
| 5 Quizzes @ 24.2 pts each: | 121 | 7.14% |
| 1 Oral Design Report (TEE) @ 300 pts: | 300 | 17.70% |
| TOTAL | 1695 | 100.00% |

LETTER GRADES

Letter grades in CH402 as based on the points awarded in each of the graded events. At any time, letter grade equivalents can be computed by dividing your earned points by the course point total. The scale for converting point percentages to letter grades is shown in the table below. Please keep in mind that this is only an approximate scale, and exact point cutoffs for your final letter grade may vary slightly from those shown here, but will be close if not exactly the same.

| Letter Grade | Numerical Score | Letter Grade | Numerical Score | Letter Grade | Numerical Score | Letter Grade | Numerical Score |
|---|---|---|---|---|---|---|---|
| A+ | 97% | B+ | 87% | C+ | 77% | D | 67% |
| A | 93% | B | 83% | C | 73% | F | <67% |
| A- | 90% | B- | 80% | C- | 70% | | |

DESCRIPTION OF GRADED EVENTS AND GRADED EVENT POLICIES:

*WRITTEN PARTIAL REVIEWS (WPRs).* WPRs usually consist of one to three multi-concept questions on material that we cover in class or that you cover outside of class in your reading and homework assignments. WPRs are allotted the full 55-minute time period. Approved solutions will be made available after the exam and will be posted to the web site as soon as the last make-up exam is complete. Due to the effort required in producing a well-written exam, you are required to provide advance notice of absences to the extent that is possible. Cadets who know that they will be absent from a WPR must notify me **at least 48 hours** in advance. All absent cadets will be required to take a make-up or make-ahead exam.

You may request relief from a WPR OR OTHER GRADED EVENTS if you have multiple graded events due on the same day, even if the graded events are in different courses in different departments. This request should be timely enough to allow changes to the schedule and to the event. The construction of a fair and well-written graded event is a significant undertaking. Please consider this when you request relief. *Any requests for relief from an exam must be submitted in writing via email. In the request, you must include the reason for seeking relief.* You must also receive a written response from me before the schedule change is confirmed.

*RESUBMISSIONS (WPRs).* Occasionally the average on a WPR can be quite low. When the average on the WPR is sufficiently low, cadets may be offered a chance to resubmit the exam to earn extra credit points. The purpose of the resubmission is to provide an opportunity to review the material that created the difficulty on the exam. The amount of the extra credit available in a resubmission depends on the average score, and typically amounts to 5-20% of the total WPR points, added back to the initial score for reporting in CANVAS.

*REFERENCES (WPRs).* Typically, WPRs are normally open note, book, and internet. This means you should expect the exams to be challenging and that preparation and organization is required on your part. If you assume that organization and preparation is not required and that you will be able to look up the answers to the problems in an *ad hoc* manner during the exam, you will encounter difficulty. Even though the available references are quite extensive, significant work is required to organize these references and to know where to find solutions. The bottom line is that students who are prepared for exams generally do better. Furthermore, work must be individual, and you may not collaborate by sharing files or any other information with other cadets during the exam, but group preparation before the exam is encouraged. Any references from outside of my course must be documented.

*QUIZZES.* There will be five quizzes during the second block on design economics. The quizzes are designed to assist with preparation for the FE exam and will be FE-style (multiple choice). The quizzes are challenging so study hard for them and be ready for the day’s assignment. Your instructor may issue additional quizzes if performance is sufficiently poor.

*GRADED HOMEWORK.* Homework consists of both reading and problem assignments and is an important part of this course. The homework is intended as practice for key concepts covered in both the classroom and the reading assignments. Homework is also intended to develop your problem-solving skills and to develop your level of experience.  Sharing of homework solutions and group work is permitted, as long as *you assume personal responsibility. or learning the concepts*. Proper documentation of all help is required, and as are individual homework submissions.

You are **highly encouraged** to work on the problems using your computer with Mathematica and/or Excel. This serves two purposes. First, you will find computerized problem solutions to be useful during exams and for emailing me when you need assistance. Secondly, use of computer technology will help to develop in you an ability to organize your problem solving according to an "algorithmic approach," which is a fundamental skill in the engineering thought process. Organizing your thoughts into discrete steps in an “algorithm” is a powerful learning approach.

The purpose of graded homework is to encourage daily lesson preparation. To that end, homework problems will be collected and graded on a roughly weekly basis for the first 9 weeks of the course. Each homework problem is worth six points and there are 29 homework problems in the course for a total of 174 points. The weight is close to but somewhat less than the value of one WPR. This means homework grades can significantly raise or lower your grade. The homework solutions will be posted to the web site on a timely basis after the due date. All problems are required and must be submitted with a cover sheet. Homework problems will be graded as follows. Correct Work shown with correctly answer is six points. Work shown with an incorrect answer two points. Answer without work is zero points. Work without a cover sheet is zero points. The grading rubric is shown below.

| Grade | Attributes |
|---|---|
| 6 | Cadets present complete problem solution and answers are correct. |
| | |
| 2 | Cadets present problem solution but answer is incorrect. |
| 1 | Cadet presents minimal work and answer is incorrect. |
| 0 | Answers shown with no work. |

**Rubric Procedure:**

1. Detailed grading comments will not be provided by the instructor.
2. The instructor will notify the class when the assignment has been graded and the approved solution posted.
3. Cadets are responsible for reviewing the approved solutions and finding mistakes.
4. Cadets may then resubmit problem sets after grades have been posted.
5. Resubmissions must be submitted in Canvas within the suspense, generally 48 hours after notification of posting (weekends and holidays included). Beyond that time, resubmissions will not be graded.
6. Corrections must include a single pdf document with a cover page and a new title (e.g., PS10 Corrections). The instructor will find your resubmissions in Canvas. You are <u>not</u> required to email the instructor when you have made a submission. Other documents such as Mathematica or Excel files may also be submitted to support your work, but the pdf is required.
7. Your resubmission must identify what your error was in the initial submission. You must also repair the error and verify the correction.
8. You may use the posted solutions to identify mistakes in your work. However, simply copying the instructor solution for the resubmission without correcting the initial submission will not change your grade.
9. Initial grade must be greater than 1/6 to be eligible for a resubmission.
10. The maximum score for a resubmission is 5/6.

Homework may be submitted in two ways. You may submit an electronic document or a printed or neatly hand-written paper document. Electronic submissions must be in pdf format in a single pdf document, contain a CAC-signed and CAC-initialed cover page, and be uploaded to Canvas. Printed paper documents must include printouts of any Mathematica or Excel files used to solve the problem. Each version must be complete. You may not submit part of the document in print form and part electronic. IMPORTANT NOTE: Graded homework MUST be documented in a manner that is consistent with the Documentation of Academic Work (DAW). According to the DAW, a title page with your signature is also required for either type of submission. This includes all out-of-class assignments, including problem sets, capstone problems, IPRs, etc.

*LATE HOMEWORK POLICY.* Homework may be submitted late for a cut of 1 point per problem day (weekends and holidays included). Date and time of submission must appear on cover page on the late assignment, or it will not be accepted. Late assignments may not be submitted for a re-grade.

*SMALL DESIGN PROBLEMS.* There will be five small design problems during the T- and S-hour labs. These design problems are to be completed within the 2-hour window and are intended to act as tutorial exercises for the capstone design problem. That is, they are somewhat more difficult than a typical homework problem and may require group work. Completing these problems will help develop additional skills you will need for the capstone project.

*DESIGN PROJECT*. The final portion of this course provides a comprehensive design problem that you will work on as a major part of your grade. Including the IPRs, the design project is worth 47.2% of the course grade, and **you must pass it in order to pass this course**. Projects will be completed in groups. The design problem includes a written report submitted on Lesson 40. Late reports will receive a grade of 0.

Design reports must be consistent with Chapter 11 in your textbook. Table 11-1 on page 472 will be developed into a grading rubric. Design reports MUST be documented according to the latest version of “Documentation of Written Work.” As per that document, an acknowledgment page is also required for all written work. The USMA documentation policy is straightforward and is also in accordance with accepted professional ethical practice. The intent is simple. You must identify all outside sources of ideas that are not your own. This means that if an idea did not originate with you, you must identify the source. To do otherwise is inconsistent with the principles of the Cadet Honor Code, the Engineering Code of Ethics, and the stated goals of the US Military Academy. Furthermore, failure to document an idea is illegal in the larger civilian society, and can result in loss of engineering licensure, fines, and even incarceration in extreme cases.

<u>CLASSROOM ACTIVITIES AND POLICIES</u>:

Classroom activity will include interactive discussion and execution of assigned study material, homework problems, or other pertinent topics. Classroom work will initially be predominantly problem-solving sessions. During the second half of the semester, classroom time will be allocated to independent study and research on your design problem. However, there will be times when your instructor will give group guidance when pertinent to the project.

Classroom policies are governed by USCC SOP Cards 800-812. Two specific issues that have arisen in recent semesters are consumption of food and beverages, and de-blousing. These policies are discussed below, and also apply to CH400.

Consuming food in the classroom is prohibited at all times in Bartlett Hall. Inside the classroom means inside the door. This policy is not open for negotiation. Violation will result in immediate verbal notification and COR. Food is allowed in the hallway and in the AI room across the hall. Food is not allowed in the classroom during evenings and weekends.

Beverages are allowed in the classroom under the following conditions: Beverages except plain water must be in a closed container. Beverage policy will be revoked if (1) the instructor finds any residue on or near the computers or any beverage or food-associated trash left behind in the classroom, or (2) the instructor hears any beverage-associated noises during class, or (3) the instructor or other cadets are distracted in any way by consumption of beverages. This policy is not open for negotiation. Violation will result in immediate verbal notification and COR.

ADDITIONAL INSTRUCTION (AI).

Liberal amounts of AI are available in this course and AI is encouraged, especially during the design project. You may stop in at any time during regular business hours (0700-1600) except class time, and if I am available, I will meet with you. I strongly encourage the use of appointments where feasible since they will guarantee my presence and one-on-one attention. Appointments always have priority over walk-ins. So, if a cadet is in an appointment with me, you may be asked to wait if you are trying to see me as a walk-in at the same time.