2021 ASEE ANNUAL CONFERENCE
Virtual Meeting | July 26–29, 2021 | Pacific Daylight Time
Paper ID #33626

Work in Progress: Techniques for Including Chemical Process Safety and Environmental Compliance in a Chemical Engineering Capstone Design Course

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Introduction

The capstone design course in the senior year of the chemical engineering curriculum at Texas A&M University-Kingsville serves as a transition for students completing their undergraduate studies and preparing to enter the engineering workforce. As such, the capstone course is an appropriate point in our curriculum for instruction in process safety and environmental compliance, since these topics are closely aligned with the design of chemical processes. An opportunity to improve instruction in these areas in our capstone course occurred as the result of an Accreditation Board for Engineering and Technology (ABET) accreditation visit several years previous, in which a need to strengthen the process safety instruction in our chemical engineering curriculum was identified by the reviewer. Additionally, chemical process safety and environmental compliance are important engineering topics for students to have exposure to, if they accept a job in a production, design, or consulting environment in the refinery or chemical process industries. More than half of our chemical engineering students that have an offer at or soon after graduation take positions at local and regional refinery or chemical process plants. This includes a small fraction of students that take a position in an environmental, safety, and occupational health department within a plant. The aim of this work is to share the instructional approach on safety and environmental compliance in our capstone course to obtain feedback from other design education experts to improve our instruction.

The need for enhanced process safety instruction in chemical engineering curricula has been recognized for a while in our discipline [1], [2], [3]. A greater awareness of this need resulted from the T2 Laboratories runaway reaction and explosion that occurred in Jacksonville, Florida in 2007 [4]. This event served as an impetus for ABET to specifically include process safety as a required instructional component in chemical engineering curricula in 2012 [2], [5]. This renewed interest in process safety also led to a collaboration between industry and the Center for Chemical Process Safety (CCPS) of AIChE to offer three-day process safety faculty short course during the summer starting in 2016, of which one of our authors is a graduate [2]. Over the last six years, our department has incorporated lectures and assignment activities on process safety and environmental compliance into one or both of the two-course capstone design sequence, similar to the approach of other departments in the U.S [1], [4], [5], [6]. One of the capstone design instructors draws upon his experience from a 25-year career in the consulting industry to teach these topics. Students in our program are not exposed to concerted instruction in chemical process safety in chemical engineering courses prior to the capstone design course sequence, but are only instructed in laboratory safety in chemistry, physics, and unit operations lab courses.

Approach to Process Safety and Environmental Compliance Instruction

Process safety topics are covered in both of the sequential chemical engineering capstone design courses at Texas A&M University-Kingsville, while the environmental compliance topic is covered only in the spring semester capstone design course. The process safety instruction consists of an introductory lecture in the first (fall semester) design course and two lectures of greater detail in the second (spring semester). The introductory lecture in the fall semester focuses on orienting the students to the risks that fires, explosions, and accidental chemical releases pose to safe chemical process operations, and the concepts of risk-based process safety (RBPS) management systems that many industries use to recognize and reduce the probability of catastrophic chemical events. In the fall semester, the instructor introduces the students to one or two of the videos provided on the U.S. government Chemical Safety Board website, so that the students begin to recognize that design and operational maintenance issues are frequently the cause or contributor to catastrophic chemical process events. No quizzes or assignments are included with this short introduction to the topic in the fall semester course.

In the second (spring) semester of the capstone design course, the lectures and assignments on process safety are expanded from that given in the first semester. Some of the assignments described herein are 500-word essay writing assignments that serve a dual purpose. The second semester capstone course is a required writing intensive course for the chemical engineering major at Texas A&M University-Kingsville, and each student in the course meets this requirement by writing a total of ten 500-word essays over the duration of the semester. The process safety lectures in this semester include presentations on identification of hazards and risks that most commonly occur in chemical process systems, introduction to RBPS management systems commonly found in the chemical industry, and an introduction to process hazards analysis, which leads to the hazard and operability study (HAZOP) analysis. Additionally, the instructors discuss the multiple approaches that industry takes within their chosen RBPS system to minimize operational and maintenance risks and thus minimize catastrophic events. These approaches include techniques such as post-mortem review of accident near misses, appropriate maintenance and periodic testing of process monitoring equipment, and utilizing management of change (MOC) to identify potential problems when chemical processes are modified or updated.

Several different assignments, both individual and group, are given to the students to assess their understanding of process safety. Based on the lectures described above, the students are given two writing assignments, the first on process hazards and the second on a HAZOPs analysis. The students are directed to use their chemical process from their ongoing senior design project as the subject for these two writing assignments. In the case of the HAZOP, the students are encouraged to work with their design group to develop a HAZOP chart, but they are required to

write their essay individually. The students are also required to incorporate the technical material developed from these writing assignments into their capstone design project final report. The prompts for these two writing assignments are given below [7]:

Process hazards

> "Prepare a 500-word project memorandum that presents your understanding of the chemical and process hazards associated with your group's chosen process. We have recently discussed the three types of hazards, namely flammability, reactivity, and toxicity that can be associated with any chemical process. We have also discussed how the hazards can manifest themselves in dangerous scenarios during production (in the variety of unit operations your process uses), storage, or transport. I request that you engage your group in a brief discussion or brainstorming session to come up with possible hazardous scenarios unique to your process which, if left unchecked, unrecognized, or otherwise not addressed adequately in process design, could lead to catastrophic leaks, fires, or explosions. You may conduct this hazards assessment analysis for either your entire process, one portion of your process (e.g. the reactors unit), or simply one unit operation. For each scenario you discuss in detail, be sure that you present in your memo the type of hazard involved, safety measures you would recommend building into the design to make it inherently safe, and any maintenance activities you would recommend to prevent disastrous chemical accidents. It would be helpful to include in your memo a few values for flammability and toxicity of your process reactants and products, preferably in a table format."

HAZOP analysis

> "Prepare a 500-word project memorandum that presents a HAZOP analysis of a single process unit (one block) from your senior design project process. Present the HAZOP analysis in a single table in your MS Word document. Please refer to the "Lecture 5" Powerpoint slides on Blackboard for guide words, parameters, and the preferred format of the HAZOP table (Slides 9 thru 15 in the Lecture 5 slide deck, or Table 26.5 of the course textbook, Turton et. Al. 4th Ed.). Note that, if your HAZOP table is entered in Word, the words in the table will be included in the word count for this assignment. I encourage you to develop the HAZOP table elements (deviations, causes, consequences, and actions) by conducting a group brainstorming session. Then each student will write their individual memo based on some or all of the results from that brainstorming

session and the resultant HAZOP table. You may prepare your HAZOP analysis on a reactor, separator, distillation tower, tank or other unit in your process."

An additional individual assignment the instructor assigns to the students include a quiz on an assigned CSB video, with questions listed here [7]:

Process safety video quiz

"A. What was the original chemical hazard (flammability, reactivity, or toxicity) in this accident? What was the chemical that posed this hazard?

B. What actions did the operators perform that were directly linked to the explosion?

C. Which Risk-Based Process Safety (RBPS) pillar or pillars (see RBPS diagram on next page) were not adhered to, and thus contributed to the losses in this process accident? If you list more than one, put them in an order of greatest to least impact upon the incident.

D. Using the guide words and parameters in the Lecture 5 HAZOP slides, fill in one row of the HAZOP table given below to represent what went wrong in this accident. You should fill in the columns 'parameter', 'deviation', 'cause', and 'consequence', but not 'action', since that refers to a proposed to mitigate the hazard.

E. If you worked as an engineer in this process unit before the accident, describe two things or actions you could have suggested be done or implemented that might have prevented this accident?"

Finally, the instructor also has the students develop their skills in a group-based HAZOP workshop activity (not graded), with each group given a different chemical process description from Appendix B of the course textbook [8], and a specific assigned unit operation within that process. The instructor has found, over several years of teaching HAZOP analysis that many students fail to fully understand the prescriptive nature and logical progression of the columns in the HAZOP table, when only introduced through the instructor lecture. For this reason, one of the instructors developed a workshop several years ago to address this challenge, and allow the students to develop their skill and understanding of the HAZOP through a hands-on experience. . The prompt for the HAZOP workshop is provided below [7], and each group of students is given a different process and unit operation to conduct their HAZOP. Examples that have been assigned to groups in the past are the reactor in the dimethyl ether process, a reactor in the maleic anhydride process, or a tower in the toluene hydrodealkylation process.

Prompt for HAZOPs analysis team workshop

1. “Read the process description and kinetics provided in your file
2. Review the PFD; review the stream conditions and components near (before and after) the designated unit operation; Note that some P&ID elements are included on the PFD.
3. Understand hazards & toxicities for all chemicals involved. Search for info http://www.cdc.gov/niosh/npg/ or on Wikipedia, etc.
4. Write out a statement that likely represents the unit operation “design intent”
5. Pick out a guide word and a HAZOP parameter to begin with
6. Write down specific deviations that would fall under that “guide word / parameter”
7. Discuss whether each deviation may result in a significant consequence. If not, then delete that particular “deviation” from the table
8. Enter an “action” that could be used to mitigate chance of occurrence

NOTE: “have operator check [something on process]” is not a suitable entry for “action” in the HAZOP table”

The environmental compliance instruction that is provided in the second capstone course relates to the waste streams emanating from each groups’ chemical process under design. First of all, the students are introduced to the primary federal regulations that regulate industrial emissions of air and water. The students are then required to identify the components of their various liquid and air waste streams that are subject to federal or state environmental regulations. The students then identify common treatment techniques for the stream pollutants, with a goal of discharge levels being within typical compliance standards. Since the design course is not a detailed environmental treatment course, the objective here is limited to qualitative assessment. The prompt for this writing assignment is given below [7]. The technical material developed for this assignment is also incorporated in the student’s capstone design final report

Process environmental wastes

> “Prepare a 500-word project memorandum (same format as requested for WIA #2) describing the impacts your process likely may have on the environment, principally through discharge of waste streams. This memo should be prepared based on your understanding of your process and the known or potential waste streams from the process if it were to be constructed and operated. The most

direct impact will be discharge of a waste stream that will have a potential to pollute the environment. Please consider all three primary environmental media, namely air, water, and land. Additionally, review the RCRA and SDWA documents referred to in the lecture, and provided to you on Blackboard, to assess whether any of the possible wastes from your process are explicitly regulated (for example, the carcinogen benzene has an MCL under the SDWA and also is a characteristic hazardous waste). The two documents on Blackboard are EPA Haz Waste Listings and Federal MCLs. Additionally, identify potential process modifications that could be included in your design to minimize waste discharges."

Results and Conclusions

Student scores on assignments and ABET student outcome assessments serve as evidence of the effectiveness of this process safety and environmental compliance instruction in our capstone courses. In the writing assignments, technical content counts for 60% of the assignment grade. For the three writing assignments on chemical process hazards, the HAZOPs analysis, and process environmental wastes, the technical content scores over the last three years range from 82 to 92, with an average of 87.2. The year-by-year record for the technical content scores was 83.0 for spring 2018, 88.9 for spring 2019, and 89.6 for spring 2020 offerings of the second capstone course. Course section average scores for the quiz based on CSB video ranged similarly from 82 to 91. The writing assignments on these topics serve an additional purpose beyond the writing intensive requirement, in that the technical material developed on each topic, as it relates to their specific senior design project chemical process, is a required component in the group's mid-term and final technical project reports. These project reports have served as assessment instrument for ABET student outcome 2 "an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors". Since his ABET student outcome includes safety and environmental aspects, assessments for outcome 2 represent a measure of efficacy on process safety and environmental control instruction in our capstone course. The outcome 2 assessments for our second capstone design course are 2.82 (spring 2017), 3.30 (spring 2018), 3.15 (spring 2019), and 3.36 (spring 2020), based on a 4-point scale. The scoring and assessment results described here indicate moderate rising trends over the last several years, which suggests that the approach described herein for process safety and environmental compliance instruction is effective. A separate pre- and post-course survey on student knowledge regarding process safety and environmental compliance has not been conducted to date but is contemplated for future years of this course offering. Additionally, requiring the senior students to complete SACHE modules on process safety may be considered, however a negative aspect would be the additional time demands in the final semester capstone course. The current spring-semester capstone course is a 3-hour course, however the student

workload is closer to a 4-hour course because of the writing intensive requirement, and our curriculum currently has no room for credit hours expansion.

References

1. Amaya-Gómez, R., Dumar, V., Sánchez-Silva, M., Romero, R., Arbeláez, C., and Muñoz, F. (2019). Process safety part of the engineering education DNA. *Education for Chemical Engineers*, vol 27, p. 43-53.
2. Schlup, J. R., Anthony,. J L., Hohn, K. L., Aiken, C., and Frampton, C. (2019). Industrial-academic collaboration to teach chemical process safety in *8th Process Safety Management Mentoring Forum 2019, at the 2019 AIChE Spring Meeting and 15th Global Congress on Process Safety*, p 254-262.
3. Whiting, W. B., Shaeiwitz, J. A., Turton, R., Bailie, R. C. (1998). Fitting the essentials into the ChE curriculum: ethics, professionalism, environmental health & safety in *Proceedings of the 1998 Annual ASEE Conference*, June 28, 1998 - July 1, 1998.
4. Dixon D. J., and Kohlbrand, H.T. (2015). Lending Industrial Experience through Reactive Hazard Examples in University Safety Instruction. *Process Safety Progress* vol. 34 pp. 360–367.
5. Willey, R. J., Carter, T., Price, J., Zhang, B. (2020). Instruction of hazard analysis of methods for chemical process safety at the university level. *Journal of Loss Prevention in the Process Industries*, v 63, January 2020.
6. Vaughen, B. K. (2019). An Approach for Teaching Process Safety Risk Engineering and Management Control Concepts Using AIChE's Web-based Concept Warehouse. *Process Safety Progress* vol. 38, no.2, pp 1-18.
7. Alexander, M.L., Course Notes for CHEN 4317 Chemical Process Design III, Texas A&M University-Kingsville, Spring 2020.
8. Turton, R., Shaeiwitz, J. A., Bhattacharyya, D., Whiting, W. B. *Analysis, Synthesis, and Design of Chemical Processes*, 5th ed, Prentice Hall, Boston, MA 2018.