SH&E TEXT FOR TEXTBOOKS

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Abstract

Safety, health, and environmental issues are critical in the development, design, operation and maintenance of a chemical plants. Many chemists and chemical engineers acquire major responsibilities in these areas within industry. In an undergraduate curriculum, however, safety is rarely discussed. At many colleges and universities, safety oriented courses are offered as electives, which means that many students never really learn about safety as an undergraduate student.

The Safety and Chemical Engineering Education (SACHE) Committee, a group within the American Institute of Chemical Engineers (AIChE), has been working on integrating safety into undergraduate chemical engineering programs for some time now. The ultimate goal of the SACHE Committee is to create a safety culture in our young professionals, by adding elements of safety to the undergraduate curriculum. The idea is that if students are exposed to safety in small quantities throughout their education, it will become a part of their inherent thinking within school and while working as a professional within the chemical industry.

One of SACHEs current projects is called SH&E Text For Textbooks. The goal of this project is to design text materials, examples and problems (with solutions) that can be integrated into the existing textbooks that are used in undergraduate courses. According to professors associated with SACHE, this will be the most effective method of integrating safety into undergraduate coursework.

INTRODUCTION

Safety issues are critical in the development, design, operation and maintenance of a chemical plant. This is also true for health and the environmental issues. (When reading this article, recognize that we use safety to represent safety, health, and the environment.) In this area of safety, many chemists and chemical engineers accept significant responsibilities within industry. In an undergraduate curriculum, however, safety is a scarce topic. At many colleges and universities, safety oriented courses are offered only as electives, which means that many students never really learn about safety as an undergraduate student.

The Safety and Chemical Engineering Education (SACHE) Committee, a group within the American Institute of Chemical Engineers (AIChE), has been working on integrating safety into undergraduate chemical engineering programs since 1985. SACHE is a committee within the Center for Chemical Process Safety (CCPS). CCPS was formed in 1985 by the American Institute of Chemical Engineers (AIChE) immediately following the Bhopal accident; its objective is to help the chemical industry prevent accidents of this type. The detailed objectives of CCPS include the development and dissemination of safety related materials, and help universities add an element to safety to their core courses. The SACHE Committee is responsible for this latter objective.

SACHE develops about six products per year to assist professors add safety to their courses. The products include a) case histories, b) safety lectures, c) problems and solutions, and d) annual safety workshops (three-day workshops on an industrial site for 25 professors). These products are given to each member university for an annual fee of $ 300. The products have a value exceeding $ 1000. The successful buy-in of our chemical engineering departments is manifested by the membership exceeding 125 university chemical engineering departments.

Up until 2001, SACHE focused on a) safety and b) chemical engineering departments. In 2001, SACHE expanded the focus to include health and environmental issues; and discussed the possibility of including chemistry departments. The inclusion of chemistry departments is a logical extension because chemists and chemical engineers make the major decisions concerning our chemical plants. To learn about other SACHE projects, visit www.aiche.org/sache/sachenews.htm.

The ultimate goal of the SACHE organization is to create a safety culture in our young professionals, by adding elements of safety to the undergraduate curriculum. The idea is that if students are exposed to safety in small quantities throughout their education, then it will become a part of their inherent thinking as a student and when working as professionals.

This safety culture will help our future professionals (chemists and engineers) to work together more effectively; that is, by having a common motivation to develop and install safe processes in our chemical plants. One important concept, for example, that must be understood by chemists and engineers is inherent safety. Inherent safety is described in paragraph IA.

BACKGROUND

In a review of the accident history within the chemical process industry, one will find that the number of large accidents continues to increase every year. The consequences are deaths, injuries, and environmental damage. There is currently no sign that this accident performance will improve. The causes are the complexity of chemical processes, the older age of our plants, and larger plants. It is also possible that a contributing factor (a route cause) is that our university educational environment neglects the important subject of chemical process safety.

Only a fraction of our practicing chemists and engineers have the appropriate safety culture to positively impact this negative performance. Just as a professional culture is developed in the university, an appropriate safety culture can and should be developed in the university. In this endeavor, we need our universities to:

Teach safety problem solving methods, safety concepts, and theory.
Teach students the consequences of neglecting safety.
Motivate students to continue their education in process safety after graduation.

NSF has recently funded a Proof of Concept project to identify key concepts and effective methods to assist our university professors to develop this safety culture within their students. The goals of this project are to:

- Identify class exercises and homework problems for each core course.
- Develop lectures or exercises for each course, using different teaching concepts.
- Assess the effectiveness of each method.

The educational materials will utilize effective pedagogical techniques and methods. The result of this project, currently developed for engineers, should also be applicable in other undergraduate programs. SACHE will publish and distribute these materials to member departments, and the products will eventually be made available via the internet (SACHE or WSU websites).

The initial phase of this project included an informal survey with professors to acquire their recommendations for developing this culture. Some enlightening and encouraging comments and recommendations included:

- Periodically disperse the fundamentals of chemical safety while teaching the fundamentals of the core courses.
- Emphasize the importance of the fundamentals within the core course (not replace these fundamentals with safety).
- Mention safety periodically and as transparent as possible (i.e. make safety a true part of the students fundamental knowledge).
- Develop better safety orientations for every laboratory experience. Emphasize the practical side of handling chemicals, to complement the students fundamental understanding.
- Develop SH&E Text For Textbooks to assist authors in adding elements of safety within their texts. Develop text and problems that can be readily utilized via a simple cut and paste.

Although our NSF project has several objectives that address these recommendations, this particular paper covers SH&E Text For Textbooks. The goal of this project is to design text materials, examples, and problems (with solutions) that can be integrated into the existing and future textbooks used within chemistry and chemical engineering courses. This Text For Textbooks project is focusing on the following subjects:

Stoichiometry
Kinetics
Design

The final product will include 3 safety sections for each textbook which contain:

Text pertaining to a specific safety topic,
An example problem and solution pertaining to that same safety topic, and
A problem for the end of the chapter, and a solution, also pertaining to the safety topic addressed within the above-mentioned text.

The products will cover major safety topics, such as: a) runaway reactions, b) boiling liquid expanding vapor explosions (BLEVE), c) permissible exposure limit (PEL), d) upper and lower flammability limits (UFL & LFL), and e) inherent safety.

In the development of our products, we are using available materials from SACHE and various websites:

OSHA www.osha.gov
EPA www.epa.gov
The Center for Disease Control and Prevention (CDC) and the National Institute for Occupational Safety and Health (NIOSH) http://www.cdc.gov/niosh/homepage.html

- US Chemical Safety Board http://www.chemsafety.gov/

SH&E TEXT FOR TEXTBOOKS

The following paragraphs illustrate the format that will be used for our product for the three textbooks: I.) Stoichiometry, II.) Kinetics, and III.) Design. For each textbook, we will have four sections: a.) Text, b.) Example Problem, c.) Example Problem Solution, and d.) a problem and solution for inclusion with the end of chapter problems. This end of chapter problem and solution will not, however, be illustrated in this article.

Examples for stoichiometry, kinetics, and design textbooks are shown below.

I. Stoichiometry

A. Text for Green Engineering & Inherent Safety

Green engineering (and inherent safety) is the design, commercialization, and the use of processes and products, which are feasible and economical while minimizing a.) the generation of pollution at the source, and b.) the risk to human health and the environment. [1]

The concept of inherent safety is to develop and design systems that fail safely even when operators make errors or the equipment fails [2]. This can be achieved by:

Learning and respecting the chemistry/kinetics of the chemicals that are used within our laboratories and plants.
Having chemists and engineers working together and emphasizing inherent safety throughout the development, design and operation of chemical plants.
Having these professionals take full responsibility for the safety, health and environmental aspects of our plants from conception to burial.
Exploring and adopt substitutions for hazardous chemicals and process conditions with safer chemicals and process conditions.
Minimizing the accumulation and storage of hazardous chemicals on the site.
Using chemistry and processes that are safe to handle at all phases of a project.

This discipline embraces the concept that decisions to protect human health and the environment can have the greatest impact and cost effectiveness when applied early to the design and development phase of a process or product [2]. The following example will demonstrate several aspects of green engineering and/or inherent safety.

In order to explore other areas of chemical process safety (and the hazardous results associated with inadequate process safety), you may want to investigate other chemical disasters, such as:

Three Mile Island http://www.pbs.org/wgbh/amex/three/

Chernobyl http://www.chernobyl.co.uk/

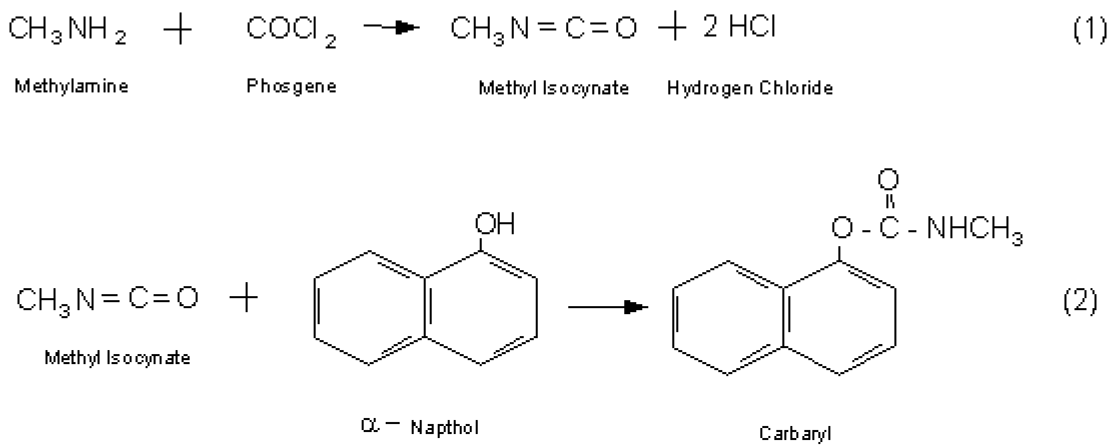
Flixborough http://www.svce.ac.in/~bnedu/Subjects/SAFETY/safety.htm

Piper Alpha www.owlnet.rice.edu/~conway/piper/ www.dme.wa.gov.au/safety/petroleum/piperalpha.htm

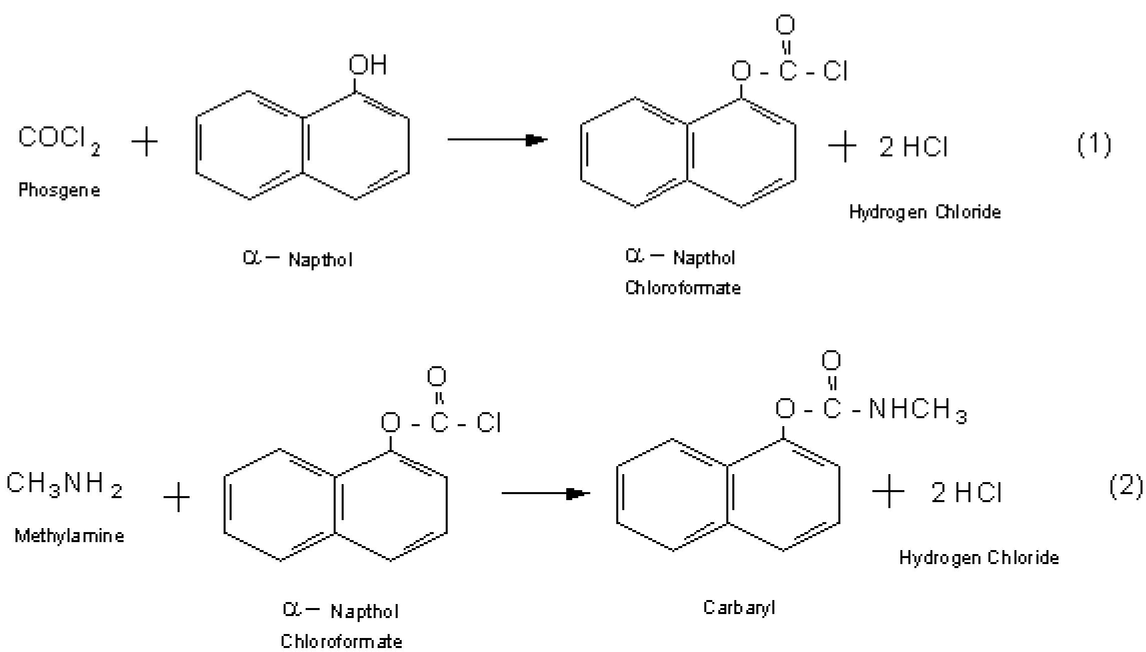
To learn more about the Bhopal disaster, visit www.bhopal.com and/or http://www.transnationale.org/anglais/forums/environnement__pollution/showmessage.asp?messageID=392

B. Example Problem:
Compare the two processes, given below, to manufacture carbaryl. Carbaryl was the herbicide produced at a chemical facility in Bhopal, India in1984. For further information on the Bhopal accident, refer to [2], [3].

Process 1:



Process 2:



Assume that you are the manager of an environmental, health, and safety department within a small chemical company, and that you have the responsibility to recommend the best process. Also assume that you know the following chemicals are on OSHAs List of Hazardous Chemicals [4]:

Methylamine

Phosgene
Methylisocyanate (MIC)
HCl

Some of these chemicals are more hazardous than others. In fact, MIC was the chemical released in Bhopal, India and was responsible for at least 2000 casualties [3]. Using what youve learned about the concept of inherent safety, evaluate the two processes for producing carbaryl, discuss which one should be adopted, and explain your thought process.

C. Example Solution:

Process 2 is preferred, since the formation of methyl isocyanate (MIC) is avoided. The concept of avoiding the use hazardous chemicals is an important component of inherent safety. Since phosgene is also hazardous, it should not be stored; that is, it should be manufactured and consumed in chemical processes immediately.

The HCl effluent is also a hazard that needs to be safely handled and disposed.

II. Kinetics

A. Text: Runaway Reactions

Most reactions in industry are exothermic, which means that energy is generated as a result of the chemical reaction. For any reaction, one can calculate the heat generated as a function of the temperature within the vessel. In order to maintain control of this reaction, the heat that is generated throughout the reaction must be continuously removed from the system. If the generated heat is not removed, the system runs the risk of running away. Figure 1 shows the heat generated and removed as a function of temperature.

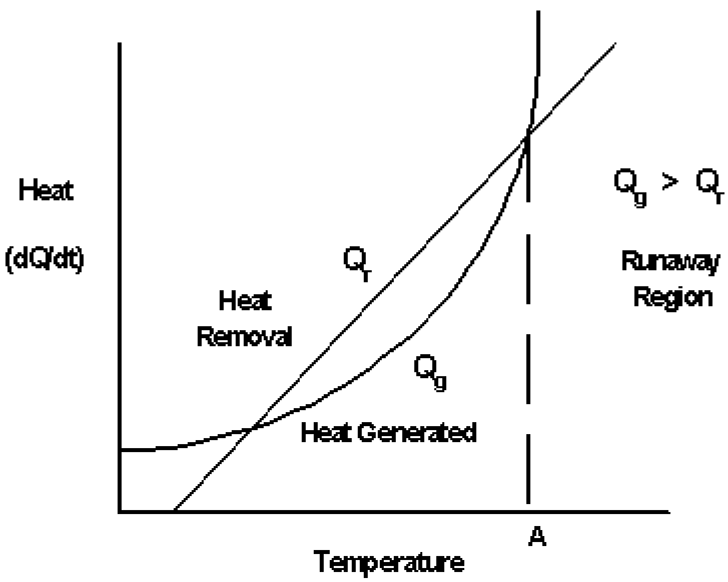


Figure 1. Runaway Reaction Scenario

A runaway occurs when the heat generated is greater than the heat removed; that is, $T > T_A$. In an industrial environment, chemists and engineers are responsible for preventing runaways and/or mitigating the consequences of runaways.

B. Example Problem:

Explain what can happen (physically) in a reactor with an exothermic reaction when the temperature begins to rise. Keep the Arrhenius equation in mind:

$$k = Ae^{-\frac{E_a}{R_g T}} \quad (1)$$

C. Example Solution

For an exothermic reaction, as T increases, the reaction rate will accelerate exponentially and the heat generated will increase exponentially. The cooling system must be capable of removing this generated heat, or a runaway reaction will occur. When a reaction runs away, the physical damage is usually due to the pressure increasing as a function of the increased temperature. The pressure is normally the result of the increased vapor pressure of the monomer or solvent. This excess pressure may rupture the vessel or piping system. If the monomer or solvent is flammable, then the result is a large explosion with grave consequences.

III. Design

A. Text: Vacuum Purging

Inerting is the process of adding an inert gas to a combustible mixture to reduce the concentration of oxygen below the limiting oxygen concentration (LOC). Vacuum purging is the most common inerting procedure for vessels. This procedure is not used for large storage vessels because they are not designed for vacuums and usually can withstand a pressure of only a few inches of water.

Reactors, however, are often designed for full vacuum, that is 760 mm Hg gauge or 0.0 mm Hg absolute. Vacuum purging is a common procedure for reactors. The steps in a vacuum purging process include

1. Drawing a vacuum on the vessel until the desired vacuum is reached.
2. Relieving the vacuum with an inert gas, such as nitrogen or carbon dioxide, to atmospheric pressure.
3. Repeating steps 1 and 2 until the desired oxidant concentration is reached.

The following equations are used to determine the number of vacuum purges, j, and the required nitrogen to decrease the concentration, y_j, to some desired concentration. [5]:

$$y_j = y_0 \left(\frac{P_L}{P_H} \right)^j \quad (2)$$

where:

$y_i =$ final target concentration

$P_H =$ the initial high pressure

$P_L =$ the initial low pressure (vacuum)

$j =$ the number of purges

The amount of nitrogen needed is determined with Equation 3.

$$\Delta n_{N_2} = j(P_H - P_L)\frac{V}{R_g T} \quad (3)$$

B. Example Problem:

Use a vacuum purging technique to reduce the oxygen concentration within a 1000-gallon vessel to 1ppm. Determine the number of purges required and the total amount of nitrogen used. The vessel is originally charged with air under ambient conditions. A vacuum pump is used, and it reaches a vacuum of 20 mm Hg absolute, and the vacuum is subsequently relieved with pure nitrogen until the pressure returns to 1 atm absolute. The temperature is 75 deg. F.

C. Example Solution

The concentration of the oxygen at the initial and final states is:

$$y_o = 0.21 \ \frac{\text{lb-mol } O_2}{\text{total mol}}$$

$$y_f = 1 \text{ ppm} = 1\text{x}10^{-6} \ \frac{\text{lb-mol } O_2}{\text{total mol}}$$

The required number of cycles is computed by rearranging Equation 2:

$$\ln\left(\frac{y_j}{y_o}\right) = j\ln\left(\frac{P_L}{P_H}\right)$$

$$j = \frac{\ln(10^{-6}/0.21)}{\ln(20\text{mm Hg}/760\text{mm Hg})}$$

$$j = 3.37 \text{ purges}$$

Since the number of purges isnt a whole number, round up to 4 purges

The total amount of nitrogen (in moles) is determined using Equation 3:

$$P_L = (\frac{20mmHg}{760mmHg})(14.7psia) = 0.387psia$$

$$\Delta n_{N_2} = j(P_H - P_L)\frac{V}{R_g T}$$

$$\Delta n_{N_2} = 4(14.7 - 0.387)psia\frac{(1000gal)(1ft^3/7.48gal)}{(10.73psia - ft^3 lb - mol^o R)(75+460)^o R}$$

$$\Delta n_{N_2} = 1.33lb - mol = 37.2lb_{N_2}$$

CONCLUSION

Chemical process safety is critical for protecting humans and our environment. The most effective means of ensuring the safety of a process is to identify all possible hazards, and to safeguard against them. In order to realize and address possible hazards within a chemical process, one must understand the fundamentals of chemical process safety, and the hazards associated with chemical processes and reactions. Achieving a safety culture within the university may be the first step for ultimately reducing safety and environmental hazards in our chemical processes. Our SH&E Text For Textbooks is a tool designed to assist authors to help professors in developing a safety culture within academia.

The product discussed in this article is one of a group of products that are being developed in the project. And, although this project is directed towards developing materials for chemical engineering students, these same materials should also be very useful to students in any chemistry environment.

REFERENCES

[1] Allen and Shonnard, *Green Engineering, Environmentally Conscious Design of Chemical Processes*, New Jersey, Prentice Hall, 2002.

[2] Louvar, J. L. and B. D. Louvar, *Health and Environmental Risk Analysis, Fundamentals with Applications*, New Jersey, Prentice Hall, 1998.

[3] www.bhopal.com

[4] Appendix A, OSHA Standard 29 CFR 1910.119

[5] Crowl, D. A. and J. L. Louvar, *Chemical Process Safety, Fundamentals with Applications*, 2nd Edition, New Jersey, Prentice Hall, 2002.