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Developing Safety Culture in an Undergraduate Chemical Process Safety Course

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Abstract

In order to better prepare students for industry and to provide them with an appreciation of the importance of a dedicated safety culture, the Department of Chemical and Biochemical Engineering at the University of Iowa has been offering a required junior-level chemical process safety course since 1996. A major laboratory component was added to this course in 1998 to provide students with hands-on experiences to emphasize concepts learned in the lecture component of the course, particularly flammability, runaway reactions, electrostatics, explosions and relief sizing. Beyond these and other fundamentals, the course emphasizes accident prevention, inherently safety design strategies, HAZOP analysis, layer of protection analysis, and related topics. A significant portion of the lectures involve the discussion of previous accidents and how they could have been prevented through the application of techniques learned in class. Students completing this course have an appreciation of industrial hazards and how to utilize engineering principles and management techniques to minimize risk.

Introduction

Since 1996, the University of Iowa has offered a required three semester hour Chemical Process Safety course that has been taken by students during the Spring semester of their Junior year. The course will begin to be offered during the Fall semester of the students' Junior year beginning in the 2018-19 academic year. Incorporating this course into the curriculum required only a slight modification of our curriculum, which is inconsistent with the common excuse ("cannot fit it into our curriculum") given for not having a dedicated Chemical Process Safety course. A dedicated laboratory component was introduced in the 1998 offering of the course as described previously [1]. The course lecture and laboratory have been modified over the years. The current details of the course and laboratory are summarized in Tables 1 and 2. This course utilizes the textbook written by Crowl and Louvar [2] and material from many websites, including Safety and Chemical Engineering Education (SAChE) [3-5], U.S. Chemical Safety Board [6], Chemical Reactivity Worksheet [7], and AIChE Design Competition [8]. The four laboratory experiments (flammability, reactivity, electrostatics, and explosions) conducted by students in the Chemical Process Safety course are described herein.

Table 1. Details of Chemical Process Safety Course at the University of Iowa

Major Topics Covered in Lecture

Government Regulation	Reactivity
Process Safety Management	Fires and Explosions
Toxicology	Fire and Explosion Prevention
Industrial Hygiene	Relief Design
Source Models	Hazard Identification
Dispersion Models	Risk Assessment/Reliability Engineering
Flammability	Case Studies
Electrostatics	Inherently Safety Design

Homework

There are weekly homework assignments.

Quizzes

There are weekly quizzes (~15-20 min). These seem to improve the learning process and to discourage student procrastination.

Exams

There is one midterm exam and a final exam.

Topical Papers

In recent years students have written two topical papers ("opinion pieces") of 500 to 1000 words: (i) Chemical Regulation – What Is The Best Approach For The U.S.? and (ii) Chemical Plant Security: Should Inherently Design Be Required?

Laboratory Reports

There are laboratory reports for each of the four experiments given in Table 2. The reports for the flammability and electrostatics experiments are individual reports, while the other two reports are written by groups of 2 students.

Project/Presentation

There is a project involving previous AIChE Design Problems (a variety of problems are distributed among student in the class). Specifically, the report consists of (i) a literature review of the process, (ii) a process flow diagram (PFD), (iii) a discussion of safety issues, including a complete HAZard and OPerability study (HAZOP) and location of relief valves, and (iv) a discussion of how inherently safer design strategies (i.e., minimize, substitute, moderate, and simplify) can be used to make the process safer. These projects are conducted in groups of 2 or 3 students.

Table 2. Chemical Process Safety Laboratory at the University of Iowa

Laboratory Experiment	Equipment Used	Comments
Flammability	• *Minimum Ignition Energy (MIE) Apparatus • *Flammability Chamber • Miniflash Automatic Flash Point Tester (Closed Cup)	This laboratory involves determining (i) the MIE of a flammable gas, (ii) the LFL, UFL, and LOC of a flammable gas, and (iii) the flash point of pure flammable liquids and mixtures. Thermodynamics of ideal and nonideal mixtures are used to calculate the flash points of the mixtures and compared to actual measurements.
Reactivity	• Advanced Reactive System Screening Tool	This laboratory involves collecting data for four different reactions and analyzing the resulting data. Furthermore, the data are used to size relief valves for specified scenarios.
Electrostatics	• Liquid Conductivity Apparatus • Powder Chargeabilty Apparatus • Powder Volume Resistivity Apparatus • Humidity Chamber • Van de Graaf Generator • Keithley Electrometers	This laboratory involves determining (i) liquid conductivity, (ii) powder chargeabilty resulting from transport through plastic, glass and metal tubes, and (iii) powder resisitivity. The laboratory also investigates (depending on the year) the chargeabilty of humans, charge accumulation due to mixing liquids, etc. The humidity chamber allows the humidity to be controlled in some of the experiments.
Explosions	• *Minimum Ignition Energy Apparatus • Modified Hartmann Tube • Hartmann Bomb	This laboratory involves characterizing gas phase and dust explosions.

*Custom made by Fauske & Associates

Flammability Experiments

The first laboratory conducted by students in the Chemical Process Safety laboratory at the University of Iowa involves investigating flammability issues (Table 2), specifically flash points (FPs), lower and upper flammability limits (LFLs & UFLs), limiting oxygen concentrations (LOCs), and minimum ignition energies (MIEs). The FPs of pure alcohols (methanol, ethanol, propanol, etc.), diluted alcohols (diluted with water) and mixtures of alcohols are measured with a Miniflash automatic FP tester (Figure 1). The FPs of the diluted alcohols and alcohol mixtures are calculated assuming ideal and real solutions as described previously [1], and then compared with measured values. The Flammability Chamber (Figure 2) utilizes mixtures of a flammable gas (usually methane or propane), oxygen and nitrogen to determine the LFL, UFL and LOC. The minimum ignition energy apparatus (Figure 3) was used to determine the MIE of a flammable gas.

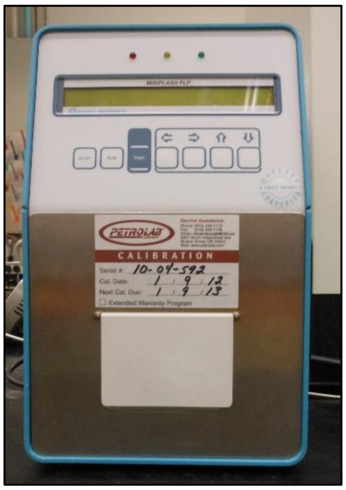

Figure 1. Miniflash automatic flash point (FP) tester (closed cup), purchased from Grabner Instruments, used to determine the FP of pure and diluted alcohols and alcohol mixtures.

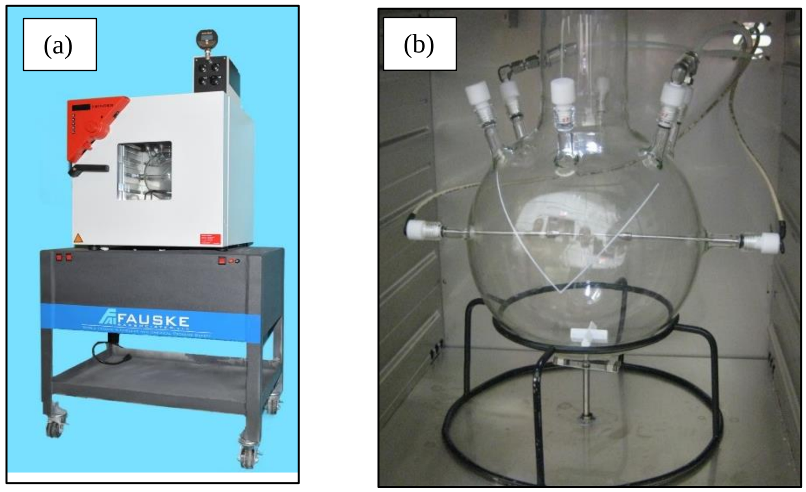

Figure 2. Flammability Chamber [(a) outside view and (b) glass test vessel], custom-made by Fauske & Associates, that is used to determine the lower and upper flammability limits and the limiting oxygen concentrations.

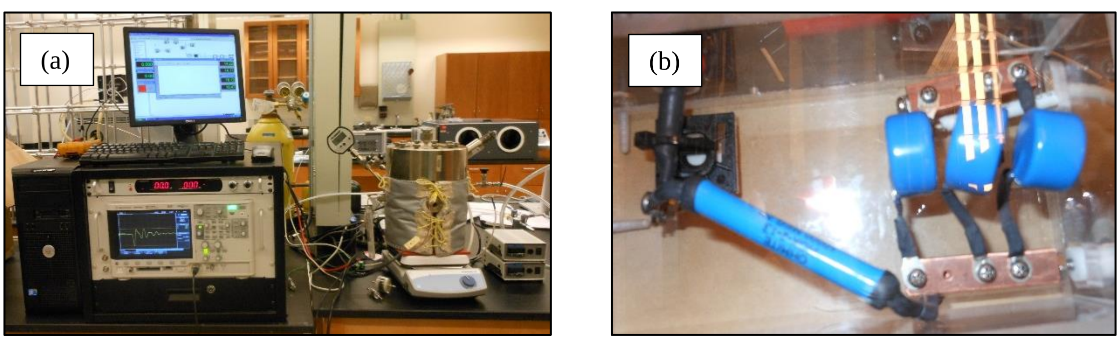

Figure 3. Minimum ignition energy (MIE) apparatus (a), custom-made by Fauske & Associates, that is used to determine the MIE of flammable gases. The amount of energy introduced to the flammable gas mixture is determined by the capacitance utilized (b).

Reactivity Experiments

The Advanced Reactive System Screening Tool (ARRST) [10] (Figure 4), purchased from Fauske & Associates, is used to evaluate the runaway reaction potential of four different reaction types. Each group of students collects data for one of these reactions, i.e., (i) methanol and acetic anhydride, (ii) ethanol and acetic anhydride, (iii) decomposition of 25% (v/v) di-tertiary-butyl peroxide in toluene (toluene serves as an inert solvent) or (iv) 0.5% (v/v) di-tertiary-butyl peroxide styrene (styrene polymerization), and then all students evaluate all 4 reactions as described previously [1]. Furthermore, a relief valve is sized for a specific scenario for each of these reactions as described previously [1].

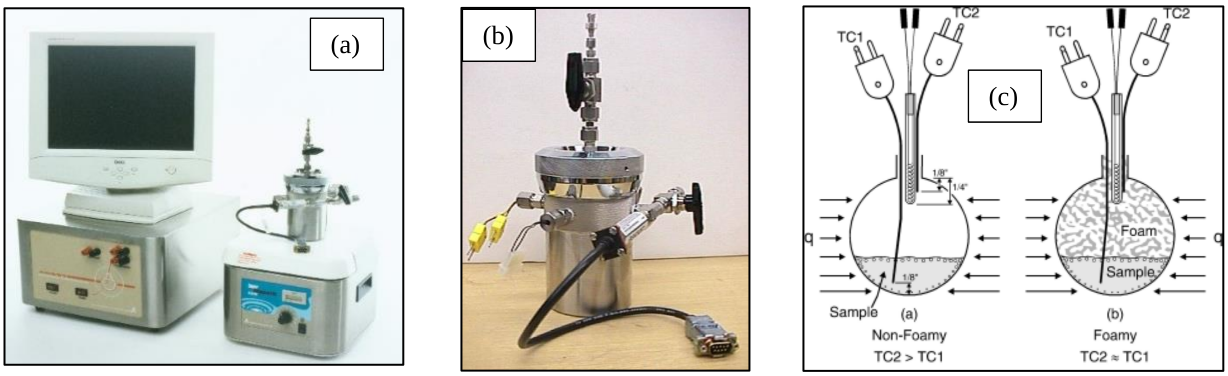

Figure 4. Advanced Reactive System Screening Tool (ARSST), purchased from Fauske & Associates, is used to determine the characteristics of reactive systems. The overall system (a) includes a stirrer, computer for data acquisition, and the vessel (b) in which the reaction takes place. The system can also distinguish between foamy and non-foamy reactions through the use of two thermocouples placed in the test cells (c).

Electrostatics Experiments

The electrostatics experiments include determining the liquid conductivity of hexane and other liquids using the apparatus shown in Figure 5. In addition, the powder volume resistivity (Figure 6) and powder chargeability (Figure 7) are determined for flour and corn starch. A humidity chamber (Figure 8) is utilized to control the humidity for the liquid conductivity and powder volume resistivity experiments Additional experiments, as described previously [1], include electrostatics involved with (i) human potential, (ii) unrolling plastic, (iii) pouring liquids and (iv) recirculating liquids. Furthermore, a demonstration of a propagating brush discharge is conducted as described previously [1].

Figure 5. Liquid conductivity apparatus purchased from Chilworth.

Figure 6. Powder volume resistivity apparatus purchased from Chilworth.

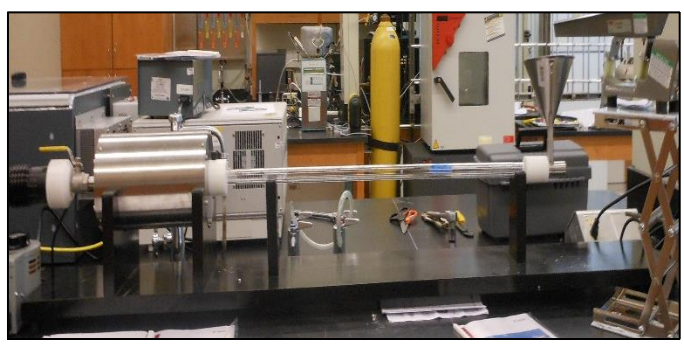

Figure 7. Powder chargeability apparatus purchased from Chilworth. This apparatus measures the change accumulated on powders resulting from transport through glass, metal and plastic tubes.

Figure 8. Humidity chamber purchased from Chilworth. This is used to control the humidity of electrostatic experiments that can be placed within the chamber.

Explosions Experiments

Gas phase and dust explosions are investigated in these experiments. The gas phase explosions (either methane or propane near stoichiometric concentration) are investigated in the MIE apparatus utilizing the highest energy level (Figure 3). This apparatus collects temperature-time and pressure-time data that is analyzed and used to size a deflagration vent as described previously [1]. Dust explosions are investigated qualitatively and quantitatively with a modified Hartmann Tube (Figure 9) and a Hartmann Bomb (Figure 10), respectively. The data collected from the modified Hartmann Tube are evaluated as discussed previously [1], while the Hartmann Bomb data include the pressure and rate of pressure increase. The deflagration index, St class and P_{max} are determined from the Hartmann Bomb data. These experiments utilize corn starch and wheat flour.

Figure 9. Modified Hartmann Tube Purchased from Adolf Kühner AG. This is used to obtain qualitative information about dust explosions.

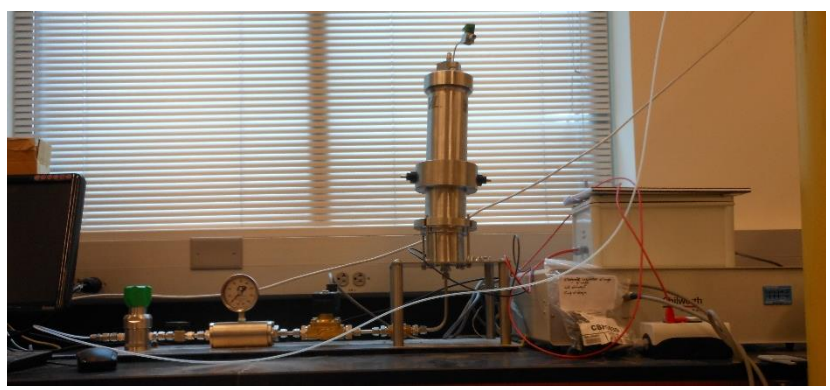

Figure 10. Hartman Bomb purchased from Chilworth. This instrument is used to investigate dust explosions and provide pressure-time data. These data are converted to rate of pressure (dP/dt) data with the equipment software.

Conclusions

The undergraduate Chemical Process Safety course at the University of Iowa is taken by chemical engineering juniors and consists of a lecture and a major laboratory component. The laboratory consists of flammability, reactivity, electrostatics and explosion experiments. The students also write extensive lab reports for each of these experiments. These hands on experiences make a major contribution to the students' understanding of chemical process safety.

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