TEACHING CHEMICAL PROCESS SAFETY: A SEPARATE COURSE VERSUS INTEGRATION INTO EXISTING COURSES

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ABSTRACT

In response to societal concerns about major disasters in the chemical process industries, chemical engineering departments have been attempting to incorporate chemical process safety into their curricula. Pressure is also coming from ABET; the AIChE Program Criteria in EC2000 require a working knowledge of the safety aspects of chemical processes.

There are three ways of incorporating chemical process safety into the chemical engineering curriculum: (1) a course or courses devoted to process safety, (2) integration of chemical process safety into existing courses and (3) a combination of the two approaches.

Having a separate course in chemical process safety puts process safety in a prominent position in the curriculum, forces the students to focus on process safety, and is the best way to deal with certain safety topics such as toxicology, industrial hygiene, dispersion models and design of relief systems. However, the students may compartmentalize safety and treat it as a topic separate from their other chemical engineering activities. Furthermore, the students may not experience a “hands-on” exposure to process safety. Finally, many chemical engineering departments do not have extra credits available in their curricula to permit a separate course in process safety.

Integrating chemical process safety into existing chemical engineering courses has the advantage of exposing the students to chemical process safety “in context”. The unit operations laboratory and the process design courses are ideal settings for integration of process safety. The instructional materials developed by SACHE make it possible to spread aspects of chemical process safety throughout the entire chemical engineering curriculum. The biggest difficulty with this approach is getting all the chemical engineering faculty to follow through with the implementation.

The Department of Chemical Engineering at Michigan Technological University uses a combination of the two approaches to teaching process safety. In 1982 a process safety program was initiated in the unit operations laboratory. In 1986 an elective course in process safety was developed. Starting in 1993, this course has been required of all chemical engineering undergraduates. There is a synergy between the process safety course and the safety program in the unit operations laboratory. The SACHE (Safety and Chemical Engineering Education) instructional materials are used in freshman and sophomore courses and, hopefully, will be used in other courses in the future.
INTRODUCTION
The Bhopal Disaster in December of 1984 (C&E News, 1985) pointed out the need for an emphasis on process safety in the chemical engineering curriculum. In response to the Bhopal Disaster, the AIChE created the Center for Chemical Process Safety (CCPS) [CEP, 1985]. One item to be addressed by the CCPS was “Safety Training.” A series of chemical plant fires and explosions in the late 1980’s further accentuated the need for chemical process safety in the curriculum. The CCPS eventually created the Safety and Chemical Engineering Education (SACHE) consortium, which began the development of instructional materials on chemical process safety. Finally, the recently developed AIChE Program Criteria for ABET’s Engineering Criteria 2000 (EC 2000) requires “...working knowledge, including safety and environmental aspects, of material and energy balances applied to chemical processes, thermodynamics of physical and chemical equilibria; heat, mass and momentum transfer; chemical reaction engineering; continuous and stage-wise separation operations; process dynamics and control; process design; and modern experimental and computing techniques.” (ABET, 1997)

Ever since the Bhopal Disaster, chemical engineering departments have struggled with incorporating process safety into the chemical engineering curriculum. ABET’s EC2000 now makes this mandatory. This paper will address three approaches to incorporating process safety into the curriculum: (1) a separate course on process safety, (2) integration into existing courses, or (3) a combination of the first two.

A SEPARATE COURSE ON PROCESS SAFETY
In some respects, a required course devoted to process safety has many advantages. Having a separate course in chemical process safety emphasizes the importance of process safety. The students must focus on process safety and will, hopefully, recognize the importance of process safety in their future careers. A course devoted to process safety is probably the best way to deal with certain safety topics such as toxicology, industrial hygiene, dispersion models, design of relief systems, hazard recognition and safety reviews.

However, one of the potential problems associated with putting process safety into a separate course is the compartmentalization of safety. The students may treat safety as a topic separate from their other chemical engineering activities and consider safety to be just another topic such as thermodynamics, kinetics, etc. Furthermore, the students may not experience a “hands-on” exposure to many operational aspects of process safety. Finally, most chemical engineering departments cannot simply add a required course on process safety to their curricula without removing some other required course. Often there are not extra credits available to justify a separate course in process safety.

INTEGRATION OF PROCESS SAFETY INTO EXISTING COURSES
According to the AIChE Program Criteria of ABET’s EC2000, the ultimate goal is the integration of process safety into all aspects of the chemical engineering curriculum. Integrating chemical process safety into existing chemical engineering courses has the advantage of exposing the students to chemical process safety “in context”. The unit operations laboratory and the process design courses are two ideal settings for exposing the students to process safety as they will encounter it in their future careers. Instructional materials have already been
developed by SACHE to make this easier to accomplish (Bethea, 1991; Crowl, Pintar, et al., 1994; Barna, Caspary, et al., 1995). There are SACHE instructional materials available for incorporating process safety principles into most of the chemical engineering courses: stoichiometry (Crowl, Hubbard and Felder, 1992), heat transfer (Willey, 1996), thermodynamics (Welker, 1996), kinetics (Willey, 1993), process control (Crowl, 1992) and computer applications (Crowl, 1997).

One disadvantage to integrating process safety into existing courses is the lack of focus on process safety. Process safety can be easily buried amongst the many other topics covered in a typical chemical engineering course. However, the biggest difficulty with integrating process safety into existing courses is getting all the chemical engineering faculty to follow through with the implementation. Not all chemical engineering faculty have the same level of commitment to process safety. As a result, many of the safety topics may never be covered in the curriculum. Development of a “safety culture” within a chemical engineering department may help to alleviate this problem.

A SEPARATE COURSE ON PROCESS SAFETY AND INTEGRATION OF PROCESS SAFETY INTO EXISTING COURSES

Having a course devoted to process safety, while integrating process safety into existing courses at the same time, can eliminate many of the disadvantages of taking either approach by itself. In fact, there can be a synergy between the process safety course and the other courses as far as achieving an effective safety education program. The process safety course can develop the safety awareness needed to make the process safety component of the other courses more effective. This will be especially true of any “hands-on” exposure to safety in laboratory courses and in design courses.

THE MTU PROCESS SAFETY PROGRAM

Chemical process safety is a focus of the Department of Chemical Engineering at Michigan Technological University (MTU). The department has been at the forefront of education in chemical process safety (Pintar, Hubbard and Crowl, 1993; Crowl, Pintar, et al., 1994; Pintar, King and Crowl, 1998). Chemical engineering students at MTU receive intensive safety training in the Unit Operations Laboratory during their senior year. This safety program was started in 1982 (Pintar, 1983 and 1985; Pintar, Hubbard and Crowl, 1993; King, 1998; Pintar, 1998). Note that this safety program was started well before the Bhopal Disaster.

A process safety course was first introduced in 1987 as an elective course. It resulted from a joint effort by MTU, Wayne State University and BASF as a part of an NSF grant. This effort also resulted in the textbook, Chemical Process Safety: Fundamentals with Applications (Crowl and Louvar, 1990); the videotape series, “Safety In The Chemical Process Industries” (Crowl and Louvar, 1989); and a study guide for the videotapes, “Safety In The Chemical Process Industries - Study Guide” (Crowl et al., 1988). Although these three items were developed at Wayne State University, the chemical engineering faculty at MTU played a collaborative role in their development and tested them in the classroom. The process safety course became a required undergraduate course in 1993.
The chemical process safety course focuses on process safety principles, especially from a theoretical standpoint, and exposes the students to industrial safety procedures that normally would not be encountered in an academic environment. The course uses the textbook and videotapes mentioned earlier. The following general topics are covered: (1) Toxicology and Industrial Hygiene; (2) Flammability, Fires and Explosions; (3) Dispersion Models and Source Models; (4) Design of Emergency Relief Systems; (5) Hazard Identification; (6) Risk Assessment; (7) Accident Investigation and (8) Case Histories. The videotapes are used to demonstrate some common industrial safety practices, such as, bonding and grounding; inerting and purging; lock-out policies and procedures; hot work permits; explosion proof areas; confined space entry procedures; personal protective equipment; safety equipment; and emergency procedures.

The process safety course is normally taken during the last quarter of the junior year. Under this arrangement, the seniors enter the unit operations laboratory course with much greater safety awareness and hazard identification skills. Process safety principles are integrated into the unit operations laboratory to give the students a “hands-on” exposure to process safety. The intention is to make process safety an integral part of the day to day work in the laboratory. The importance of safety in the unit operations laboratory is reflected in the course syllabus (Caspari, 1998); the first objective of the course is stated as: “Develop a constant awareness of safety in the laboratory so that all laboratory work is carried out in a safe manner.”

The MTU unit operations laboratory involves safety hazards typical of an industrial pilot plant: high-voltage electricity, moving shafts and belts, steam and condensate lines, gas cylinders, remotely located valves that require the use of stepladders and potentially hazardous chemicals. The chemicals include kerosene, glacial acetic acid, ethanol, sodium hydroxide, potassium hydroxide, siloxanes, mercury (in manometers and in thermometers) and nitrogen. The laboratory is maintained so that it meets OSHA standards. A lock-out policy has been established (Control of Hazardous Energy Sources - OSHA 29 CFR 1910.147, 1990). The laboratory is also kept in compliance with the chemical labeling requirements of the Right-to-Know Laws (Federal Hazard Communication Standard - OSHA 29 CFR 1910.1200, 1987). Installation of any new equipment and changes to any existing equipment are performed in compliance with OSHA’s Process Safety Management of Hazardous Chemicals Standard (PSM) including the Management of Change requirement (OSHA 29 CFR 1910.119, 1992).

The students develop their own operating procedure for running their experiments. The procedure and safety considerations are combined into a Job Safety Assessment Form (JSA). Potential hazards must be identified along with the necessary precautions that will be taken to avoid accidents. Procedures for handling chemicals, for dealing with personal contact with chemicals, for dealing with chemical spills and for proper disposal of chemical waste are required. The JSA must also indicate the personal protective equipment required for each step in the procedure, the location of the necessary safety equipment, the proper emergency shutdown procedure and the evacuation routes (King, 1998). No experimentation can be done until the JSA has been approved at a check-in with the faculty advisor and at a second on-site safety check-in with the laboratory supervisor or with a graduate teaching assistant.
The objectives of the safety program in the unit operations laboratory are accident prevention in the laboratory and preparation for industrial safety. The overall safety program is a multi-faceted approach to accomplishing these objectives with as much student participation as possible: the students receive extensive safety training throughout the year, a participatory safety program (PAWS) has been instituted, some students do a safety project as one of their experiments and safety meetings conducted by students are held regularly to review safety problems and to discuss safety issues.

At the beginning of the year, the students receive a copy of the laboratory safety manual (Pintar, 1983-Present). This manual, updated each year in collaboration with students, covers the various safety hazards in the laboratory, particularly chemical hazards. Portions of the manual explain the Michigan Right-to-Know Law, the laboratory Lock-Out Policy and Procedure and the Management of Change Policy. The first three weeks of the year are devoted to extensive safety training. The safety manual is reviewed with special emphasis on emergency procedures, on the location of safety equipment, and on Right-to-Know Law training for handling of hazardous chemicals.

PAWS (Prevent Accidents With Safety) is a special safety program that was developed as a result of a student safety project in 1989. The main objective of PAWS is to prevent accidents by involving the students in the safety program and by developing a concern for the students’ own safety and the safety of those around them. A secondary objective is to have a positive reward system rather than a negative punitive system. The PAWS Program is explained during the safety training at the beginning of the year. PAWS Forms are available throughout the laboratory for the purpose of reporting an unsafe situation in the laboratory; a key aspect of the PAWS Program is that the unsafe act or unsafe condition be corrected before the PAWS Form is filled out and submitted. Student input on the overall PAWS Program is obtained in a variety of ways including a survey of student opinions on the PAWS Program and on how it can be improved.

A Student Safety Committee is a key part of the PAWS Safety Program (King, 1998). The Safety Committee has the following responsibilities: conduct safety audits of the unit operations laboratory using the Safety Inspection Checklist (SIC) Forms, ensure that each group is familiar with the emergency shutdown procedure for its experiment, assist other groups with safety related matters, conduct the Safety Meeting, carry out a safety-related project, maintain the safety websites and update the PAWS Tracking System. Due to MTU’s strong safety culture and the required junior level safety course, the safety committee performs its assigned tasks very well.

The MTU Process Simulation and Control Center (PSCC) provides an excellent opportunity for exposing the students to industrial safety practices (Pintar, Caspary, et al., 1998). The PSCC has two highly instrumented pilot plant processes connected to a distributed control system and a plant information management system for on-line control, data acquisition and simulation. The first two phases, a jacketed reactor and a solvent recovery process, are operational.
The jacketed reactor uses a Dow Corning Corporation batch polymerization process to produce polychlorinated biphenyls (PCBs). This process was selected because it involves an endothermic reaction (no possibility of a runaway reaction) and there are no hazardous side reactions. However, the flammable reactants require special safety precautions. The solvent recovery process involves the distillation of denatured ethanol-water in a distillation column packed with Koch Flexipac I. The flammability of the ethanol requires special safety precautions.

Because of the flammability of the chemicals being used, both PSCC processes use nitrogen for inerting. The nitrogen is generated in the laboratory by using a membrane to separate nitrogen from air. The membrane separator provides a continuous supply of nitrogen, which can be a very dangerous asphyxiant. Two low oxygen level alarms are installed in the laboratory and will sound if the oxygen level in the laboratory falls below 19.5%.

In addition to learning to work as a member of a production team, the students obtain firsthand experience with common industrial safety practices such as grounding and bonding, purging and inerting, NEC classified areas, lockout policy, safety interlocks and overrides and PSM Management of Change requirements. The PSCC also is used for additional safety training. In the implementation of the Management of Change Policy, some of the Safety Committees have been assigned to do a safety review of proposed changes for the PSCC. Other Safety Committees have verified that the relief devices in the PSCC are properly sized and have established a testing program for the check valves and for the relief devices.

THE USE OF SACHE MATERIALS AT MTU
The SACHE educational materials are being used to assist in integrating process safety into the MTU chemical engineering curriculum. The SACHE videotape on Process Safety Management (Chevron, 1992) and some of the slide presentations on fires and explosions (Welker, 1992; Welker and Springer, 1993) are used in the freshman orientation course. The SACHE stoichiometry problem set (Crowl, Hubbard and Felder, 1993) is used in the mass and energy balance courses.

The process safety course uses some of the educational material developed by SACHE: computer-based safety problems (Crowl, 1997), case studies (Willey, 1994; Bethea, 1994), fires and explosions (Welker, 1992; Welker and Springer, 1993; Louvar and Schoeff, 1995), process safety management (Chevron, 1992), HAZOP (JBF Associates and AMOCO, 1992; Chevron, 1993) and guide to chemical hazards (NIOSH, 1997). SACHE videotapes and slide presentations are frequently used at the unit operations laboratory safety meetings: explosion proof areas (Page, 1993) and the Phillips’ explosion (Bethea, 1996) are two recent examples.

In the future, it is anticipated that the SACHE materials will be used to integrate process safety into additional courses at MTU.

FUTURE SAFETY EFFORTS AT MTU
Michigan Tech is converting to semesters from quarters. The semester system will become effective in the fall of 2000. The semester curriculum in chemical engineering is still under development. There most likely will be a three credit semester course devoted to process safety
and to the environment (the other topic specifically addressed by the AIChE Program Criteria of ABET’s EC2000). It is also anticipated that safety and the environment will receive special emphasis in the senior plant design courses. The safety program in the unit operations laboratory will continue and will be extended to any additional laboratory courses that are developed. Safety topics will also be introduced into other courses in the new curriculum.

Recently, members of the Industrial Safety Advisory Board of the MTU Department of Chemical Engineering reported on the results of surveys on chemical process safety at BASF and at the Dow Chemical Company. Although the sample size is small, the surveys indicate that MTU chemical engineering graduates are well prepared for industrial safety practices.

CONCLUSIONS

1. The combination of a course in chemical process safety and integration of process safety into existing courses is the most effective way to teach chemical process safety to undergraduate chemical engineering students. The safety course sensitizes the students to safety issues. The integration of process safety into courses such as the unit operations laboratory exposes the students to safety practices that will be encountered in industry.

2. Integration of process safety into existing courses can be an effective way to teach process safety provided that all or most of the faculty are committed to implementation of this approach.

3. A separate course in process safety can help to develop safety awareness and to teach safety principles, but to rely completely on such a course is the least effective way to teach process safety.

4. Many of the comments made here about process safety can be extended to environmental issues.

ACKNOWLEDGMENTS

The author acknowledges the many contributions of Dr. Daniel A. Crowl, Dr. Julia A. King, David W. Caspary and Tim Gasperich to the MTU Safety Program. Also, the author thanks the more than 1000 chemical engineering students who contributed to the safety program and, hopefully, benefited from it.

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