INTEGRATING PROCESS SAFETY INTO THE UNIT OPERATIONS LABORATORY

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ABSTRACT

Chemical process safety has been an integral part of the unit operations laboratory course at Michigan Technological University since 1982. The students are directly involved with the safety program, which is called "PAWS" for "Prevent Accidents With Safety". The main goals of PAWS are to take a positive approach to safety and to make the students responsible for their own safety and for the safety of those around them.

One student group serves as the Safety Committee for each experimental cycle. The Safety Committee inspects the laboratory at the beginning and at the end of each operating day, monitors the safety of the laboratory, and conducts the Safety Meeting for that cycle. The Safety Meeting consists of a review of any unsafe acts or safety incidents that occurred, a report on the results of the safety inspections, a presentation on an assigned safety topic, showing of a relevant videotape, and class discussion.

The laboratory is an ideal setting for exposing the student to industrial safety practices. All the OSHA regulations (PSM, Management of Change, Lock Out, and the Right-to-Know Laws) are fully implemented in the laboratory. The laboratory is operated as though it were an industrial pilot plant. The students encounter inerting procedures, bonding and grounding, NEC classified areas, safety interlocks, and safety overrides when running the Process Simulation and Control Center (PSCC) experiments.

The students should be well prepared to deal with the types of safety situations that they will encounter in the chemical process industry.

I. INTRODUCTION

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). 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); note that this is well before the Bhopal Disaster, which resulted in nationwide concern about chemical process safety. The students also take a required course, "Chemical Process Safety," during their junior year. This safety course was first introduced in 1987 as an elective course and became a required course in 1991.

By integrating process safety principles into the unit operations laboratory, the students receive 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, which states the first objective of the course as:

"Develop a constant awareness of safety in the laboratory so that all laboratory work is carried out in a safe manner." (Caspary and Ellis, 1997)

The MTU unit operations laboratory provides an ideal setting for teaching process safety and for preparing chemical engineers for safety in the chemical industry. The laboratory has two levels (each approximately 30'x85') and a third level at one end (approximately 30'x30'); the second and third levels have open bays in the middle to allow for tall columns and are equipped with overhead cranes. The laboratory equipment is of pilot-plant size and includes the usual unit operations. As a part of the PSCC (see below), a jacketed reactor and a packed distillation column have already been installed and an evaporator-crystallizer will be installed in the future.

The safety hazards typical of an industrial pilot plant are present: high-voltage electricity, moving shafts and belts, steam and condensate lines, gas cylinders, remote 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. In spite of the age of much of the equipment, 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 the PSCC 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 unit operations laboratory course meets one day a week for nine hours during all three quarters of the senior year. The students work in self-selected groups of three or four. The number of experiments required for each group varies from year to year. Currently, each group performs six experiments including participation on teams of two or three groups that run the two PSCC experiments. Each experiment usually operates on a four week cycle: one week for planning, two weeks for experimentation, and one week for writing the report.

The students receive a set of objectives for an experiment from the faculty advisor and then prepare a complete experimental plan to obtain the necessary data in order to meet their objectives. Except for the PSCC experiments, they develop their own operating procedure for running the experiment. 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. No experimentation can be done until the JSA has been approved at a check-in with the faculty advisor and at a second safety check-in with the laboratory supervisor or with a graduate teaching assistant.

II. UNIT OPERATIONS LABORATORY SAFETY PROGRAM

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.

1. Safety Training

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 and the location of safety equipment. The Right-to-Know Law training includes: the location of the MSDS's; explanation of the chemical labeling system; a list of the hazardous chemicals used in the laboratory; review of the proper handling and labeling procedures; emergency measures; spill procedures and waste disposal. The students are expected to be familiar with all chemicals used in the laboratory, including those not directly involved in their experiment.

2. The PAWS Safety Program

PAWS (Prevent Accidents With Safety) is a special safety program that was developed as a part of a student safety project in 1989; the name of this program resulted from a contest conducted amongst the students. PAWS is modeled after the SOAR Program (Stop-Observe-Act-Report) used at BASF (Wyandotte). 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.

Under the PAWS Program a group receives points for submitting a PAWS Form for any action taken to correct an unsafe act or unsafe situation. The identity of the "perpetrator" of an unsafe act is not revealed on the PAWS Form. At the end of each quarter, the group in each laboratory section with the most points is treated to dinner at an eating establishment selected by the winning group.

The PAWS Program is still evolving. One of the most difficult aspects of any safety program is preventing accidents that result from unsafe behavior. The original intention of PAWS was a strictly positive program; however, it was found during the first year of implementation that it is necessary, in some instances, to take a punitive approach to repeated unsafe behavior. The punitive approach may consist of negative points and/or requiring a written report or lecture to the class on a safety topic related to the unsafe behavior. In recent years it has not been necessary to take punitive action.

One problem revealed by the surveys of the students on PAWS was an impression amongst some of the students that PAWS is a "tattletale" system, even though the "perpetrator" remains anonymous. One reason for this impression was the issuance of negative points for unsafe acts observed and reported by students acting as safety officers (now called the Safety Committee). Under the present system the Safety Committee is asked to protect the identity of the "perpetrator" for the first unsafe act. However, in order to prevent accidents, the Safety Committee is asked to report any repeat of the same unsafe act by the same individual(s) to the laboratory supervisor or to one of the safety coordinators so that a positive corrective action can be taken.

Student participation in the PAWS Program has varied. In the early years of the program approximately fifteen to twenty PAWS Forms would be submitted during a typical quarter, most of them for equipment related situations and, in some cases, of a "nit-picking" nature. Most of the PAWS Forms were coming from the student Safety Committees. As the program evolved, student participation in the PAWS Program has greatly increased and most of the PAWS Forms have been submitted by students other than the Safety Committee.

One advantage of the PAWS Program is that it gives insight into safety problems in the laboratory before an accident occurs. Maintenance items are corrected as soon as possible. Frequently occurring unsafe acts are discussed with the class to prevent their occurrence in the future. Table 1 summarizes the PAWS Forms submitted for the last five years.

TABLE 1 -- SUMMARY OF “PAWS” FORMS

	1993-4	1994-5	1995-6	1996-7	1997-8
Number of Experiments	7	6	6	6	4
UNSAFE ACTS					
Spills	34	8	2	3	8
Dealing With Chemicals					
Chemical Labeling	13	11	5	4	6
Chemical Storage	5	3	2	10	1
Chemical Handling	7	12	5	4	5
No MSDS	0	2	1	0	0
Chemical Total	25	28	13	18	12
Housekeeping	24	7	8	9	3
Personal Protective Gear					
Eyewear	7	27	16	5	4
Footwear	4	10	3	4	4
Hardhat	0	8	6	6	2
Gloves*	0	0	0	4	1
Earplugs*	0	0	0	1	0
Other	11	6	15	2	3
Protective Gear Total	22	15	40	22	14
Ladders	15	8	2	2	1
Unattended Equipment	10	7	4	6	3
Handling Glassware	8	6	3	3	2
Lockout	5	2	0	0	1
Miscellaneous Unsafe Acts	24	14	8	11	10
Total No. of Unsafe Acts	167	131	80	74	54
EQUIPMENT PROBLEMS					
Leaks	25	11	6	24	12
Safety Equipment	18	1	4	13	14
Electrical	16	5	1	6	3
Faulty Equipment	15	6	6	9	8
Hot Surfaces	4	0	0	4	1
Odors	4	5	0	1	1
Guards Missing	3	0	0	1	0
Misc. Equipment Problems	17	13	16	13	10
Total No. of Equipment Problems	102	41	33	71	49
Safety Suggestions	0	6	2	17	7
Total Number of “PAWS” Forms	269	178	115	162	110
“PAWS” Forms From Safety Comm.	164	71	31	45	55
	(61%)	(40%)	(27%)	(28%)	(50%)

*** Included in “Other” for 1993-4, 1994-5, and 1995-6**

The most common unsafe acts involve improper protective equipment, particularly eye protection and proper footwear, and improper handling and transport of chemicals.

The Safety Committee updates a safety website that provides information on the PAWS Program and contains links to a PAWS Tracking System and to other safety information (http://chem.mtu.edu/classes/uo/uopages/safety.htm). The PAWS Tracking System contains information on all PAWS Forms including the corrective action that was taken.

Based on the surveys of the students, most students feel positive about the PAWS Program. However, in addition to the "tattletale" image discussed earlier, some students feel that PAWS and the concern about safety distract them from obtaining their data. Such an attitude must be recognized because it can very easily lead to accidents. The only effective way to combat this attitude is to continue to stress the importance of safety and to emphasize the high priority of safety within the overall context of the unit operations laboratory course.

3. Student Safety Projects

In 1982, a safety project was introduced into the unit operations laboratory course as an assigned experiment. The students are graded on the project in the same way as the students doing the other laboratory experiments. This approach is intended to emphasize the industrial philosophy that "Safety has the same importance as your primary job function" (Crowl and Louvar, 1989). During the years when the students were required to do a special project, there were safety projects that could be selected. Most of the safety improvements in the unit operations laboratory originated as student safety projects. The development and updating of the safety manual; the PAWS Program; and the installation of eyewash fountains, lighted exit signs, and a fire alarm horn in the laboratory are examples.

The safety projects are also used as a part of the laboratory safety education program. The safety committees have given lectures on OSHA regulations, the Right-to-Know Laws, SARA Title III, Lockout Policies and Procedures, NEC Classified Areas, Standards for Protective Equipment, OSHA Safety Training Requirements, PSM and Management of Change, and Biosafety Standards. Student Safety Committees have served as opposing parties in a mock OSHA Hearing on safety in the unit operations laboratory. Other safety projects involved development of safety training videotapes that were shown to the class. One Safety Committee worked with the Local Emergency Planning Committee, established under SARA Title III, in developing a Fixed Site plan for a local company and in developing the local Resource Plan. These projects have been educational for the Safety Committee and for the other members of the class.

Student Safety Committees have conducted OSHA Inspections of the unit operations laboratory and of the teaching and research laboratories of the chemistry and chemical engineering departments. The student recommendations have helped to keep the unit operations laboratory, in particular, up to OSHA standards. As a part of the Right-to-

Know Law training and as a means of making certain that the students are aware of the hazards of all the chemicals used in the laboratory, a Safety Committee gives a quiz on chemical hazards to the other students in the class. All members of a student group must pass the quiz before the group can proceed with its experiment. Most students pass the quiz the first time that they take it. At some point during the year, a Safety Committee will conduct an evacuation of the laboratory. The evacuation time is measured and all experiments are checked to make sure that the proper shutdown procedures were followed. The results have always been very good -- one minute or less to evacuate and all experiments shut down properly.

Other safety projects have involved studies of acceptable footwear in the laboratory and of the problems associated with wearing contact lenses in the laboratory. The footwear studies resulted in requiring ankle-high leather workboots but not steel-toed boots. The contact lens study resulted in the requirement that students wearing contact lenses must indicate this with a red dot on the side of the safety glasses. In conducting these two projects, the students consulted with industrial members of the department's Safety Advisory Board.

More recent safety projects have involved an investigation of the recent classification of phenolphthalein as a carcinogen by the FDA, development of a Biosafety Program for a new bioreactor, proper personal hygiene practices in the laboratory, and proper lifting techniques.

In the past every safety project required the Safety Committee to serve as safety officers in the laboratory. Originally, they issued safety citations for violations of safety regulations. This is no longer done. Under the PAWS Program, the terms "safety officer" and "safety violation" are no longer used.

One of the duties of the students on the Safety Committee is to conduct a one hour Safety Meeting during the third week of the four week cycle for each experiment (after the first day of experimentation). They review any PAWS Forms from the previous week, review any safety incidents that may have occurred, report on their laboratory inspection, make a presentation on their assigned safety topic, and show a relevant videotape. So far, these Safety Meetings are an effective part of the overall safety training program.

One of the goals of the safety program is a high level of student involvement. This is accomplished by discussion led by the Safety Committee at the Safety Meeting. Where appropriate, a vote by the students is used to make decisions on any major changes to the safety policies.

III. THE PROCESS SIMULATION AND CONTROL CENTER (PSCC)

The Process Simulation and Control Center (PSCC) is a joint effort between the MTU Department of Chemical Engineering and industrial sponsors. When completed, the PSCC

will have three 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 third phase, an evaporator-crystallizer, is in the design stage. The three pilot plant processes are (will be) located in the unit operations laboratory; the computer consoles are located in a control room overlooking the laboratory (Pintar, Caspary, *et al.*, 1997).

The jacketed reactor uses a Dow Corning Corporation batch polymerization process to produce polydimethylsiloxane (PDMS). 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, inerting, NEC classified areas, lockout policy, safety interlocks and overrides, and PSM Management of Change requirements. Because these processes so closely resemble actual industrial situations, the students enjoy running the PSCC experiments.

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.

IV. SAFETY RECORD IN THE UNIT OPERATIONS LABORATORY

One measure of an effective safety program is the number of accidents that occur. The overall safety record of the unit operations laboratory is very good. During a typical year there are no accidents or, at the most, one to two minor cuts and burns.

One minor cut occurred several years ago when a student cut his hand as a result of improper insertion of a thermometer into a rubber stopper; fortunately the thermometer

broke above the mercury level and the cut was not serious. The entire class was informed of the proper procedure for inserting a thermometer or glass tubing into a rubber stopper.

The most serious accident in the laboratory occurred early in the fall quarter of 1982. Two students received second degree burns from liquid ammonia as the result of a faulty ammonia tank (Pintar, 1983). This accident was a major factor in the development of the extensive safety program that is now in place.

In the spring quarter of 1983, a student was burned on the foot. (Pintar, 1983). Hot steam and condensate were discharged from a flexible drain line and penetrated the student's porous suede shoes. This accident led to the current footwear policy that requires that boots must be of made of non-porous leather. Another result of this accident was a requirement that all discharge lines, particularly those made of rubber or plastic, extend into the drain and be fixed in place so that they cannot whip around.

In the fall quarter of 1992 two students suffered minor steam burns as a result of improper operation and faulty design of a flexible steam line used for barrel calorimetry. The line was redesigned and the operating procedure corrected.

Fortunately, none of the above accidents caused permanent injury or scarring.

Two serious "near misses" have occurred since 1982. In the fall quarter of 1982, a student was almost electrocuted when he improperly connected a power analyzer. This incident led to a temporary requirement that a properly trained faculty member or GTA supervise the connection of the power analyzer and eventually led to hard-wiring the power analyzer into the process.

In the fall quarter of 1986, a surge tank on a compressed air line to a capillary viscometer exploded. Pieces of the tank just missed two students near the tank and would have hit a student on the lower level if the pieces were not caught by the wire mesh on the railings around the open bay. The students involved in the accident immediately proceeded with the emergency shutdown procedure for the capillary viscometer. One positive aspect of this incident was the student demonstration of the effectiveness of their safety training. Investigation of the incident revealed that the tank, designed for atmospheric pressure, was exposed to the full line pressure of 90 psig. The capillary viscometer had been built of scavenged parts and had been moved just recently into the unit operations laboratory. The system was redesigned to eliminate the need for a surge tank.

The surge tank explosion led to a thorough safety review of all the current experiments in the laboratory. Also, a policy was established that any new experiment or changes in existing experiments must be subjected to a safety review pursuant to OSHA's PSM Standard. This policy was implemented during the design of the pilot plant processes for the PSCC; engineers from BASF (Wyandotte), Dow Chemical Company, Dow Corning Corporation, and Wayne State University along with the MTU chemical engineering faculty and staff conducted a safety review of the design and operation of the processes.

All the above accidents and "near misses" were reported to the university safety office and discussed with the class to determine the cause of the accident and what should be done to prevent future occurrences. Under the current setup, the Safety Committee is asked to investigate any accidents or safety incidents and to discuss them at the Safety Meeting.

V. CONCLUSIONS

1. **The integration of chemical process safety into the unit operations laboratory is a very effective way to teach the principles of chemical process safety. The laboratory experience allows the students to apply these principles in an actual operating environment.**

2. **The safety program in the MTU Unit Operations Laboratory is accomplishing its objectives of accident prevention and safety education.**

3. **A very effective safety program can be obtained by directly involving the students in its development and implementation. A safety program such as the MTU PAWS Program, student safety projects, and regular Safety Meetings conducted by students are good ways of accomplishing this.**

4. **An industrial-like setting such as that found in the MTU Unit Operations Laboratory and in the pilot plant of the MTU Process Simulation and Control Center should give chemical engineering graduates proper preparation for the safety practices used in industry.**

VI. RECOMMENDATIONS

1. **Other chemical engineering departments are encouraged to use the approach used at MTU to integrate chemical process safety into the unit operations laboratory.**

2. **The MTU chemical engineering graduates should be surveyed to determine how well the MTU safety program prepared them for their careers as chemical engineers.**

VII. ACKNOWLEDGMENTS

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