INCORPORATING SAFETY INTO A UNIT OPERATIONS LABORATORY COURSE

JULIA A. KING
Michigan Technological University • Houghton, MI 49931

Chemical process safety is taught at Michigan Technological University (MTU) via two methods: a required junior-level lecture course and integrated into the existing senior-level unit operations course.[1] The required junior-level course typically covers industrial hygiene and toxicology, flammability, relief systems, hazard identification, risk assessment, accident investigation, and case histories. After completing this class, the students are ready to apply these topics in the unit operations laboratory, which is the major chemical engineering laboratory experience they encounter.

The unit operations course consists of thirteen different pilot-scale standard experiments (batch filtration, continuous filtration, continuous-stirred tank reactors, cooling tower, flow measurement, fluidization, liquid-liquid extraction, polymer processing, pumping a, pumping b, single-pass heat transfer, shell-and-tube heat transfer, and vacuum drying) and two industrial-scale pilot plants (PSCC, Process Simulation and Control Center, which uses the Honeywell Total Plant Solutions control system), the first being an industrial-scale pilot plant for fractionation of a water-ethanol system, and the second being a PDMS (polydimethylsiloxane) jacketed-reactor pilot plant.

The students are divided into groups of four. The members of each unit operations group remains the same for an entire academic year, and during the year, each group conducts six experiments (or cycles), two of which are the PSCC pilot plants. For each cycle, each group spends one week preparing for their assigned experiment, two weeks in the laboratory conducting their experiment, and one week writing their report.

For each laboratory cycle, one group of students is randomly assigned as the safety committee.[2] Safety is the sole duty of this group, and there is a different safety committee for each cycle. This procedure began in 1983 as a method of incorporating safety into the unit operations course. We regard safety as an integral part of the unit operations course, and student involvement in the program prevents the need for faculty/staff-mandated safety rules. Safety procedures for the unit operations laboratory course are reviewed and approved by the unit operations students, as well as by faculty/staff. This paper focuses on further integration of safety, including using Job Safety Assessments and the Internet, into the existing unit operations course.

UNIT OPERATIONS COURSE

Most of our chemical engineering faculty are involved in the unit operations course. I was assigned as the faculty member in charge of the safety committee for each laboratory cycle. Typically, the safety committee had been responsible for accident prevention and safety education, including

- Conducting safety audits of the unit operations laboratory before, during, and after the laboratory period
- Distributing "Prevent Accidents with Safety" (PAWS) forms
- Ensuring that each group is familiar with the emergency shutdown procedure for its experiment
- Assisting other groups with safety-related matters
- Conducting the safety meeting for that cycle
- Conducting other safety-related objectives that change from cycle to cycle

Basically, the committee is responsible for the safety of all unit operations students in the laboratory and is assigned to answer (or find the answer) to any safety-related questions

Julia A. King *is Assistant Professor of Chemical Engineering at Michigan Technological University. She received a BS from Purdue University (1982) and her MS (1987) and PhD (1989) from the University of Wyoming. She has industrial experience from employment at Exxon Baytown Refinery and DuPont/Conoco. Current research interests include polymer and composite materials.*

We regard safety as an integral part of the unit operations course. . . For each laboratory cycle, one group of students is randomly assigned as the safety committee. Safety is the sole duty of this group, and there is a different safety committee for each cycle.

that the students may have. The safety committee members are assigned a grade based on their performance of these duties. Due to MTU's strong safety culture and required junior-level safety course, the safety committee generally performs its assigned tasks well.

Based on my industrial experience, I led the development of the following enhancements to MTU's already strong safety involvement in the unit operations course:

- Creation of a unit operations laboratory Internet homepage with an emphasis on safety
- Development of a "Safety Inspection Checklist" for the unit operations laboratory
- Revision of the PAWS form to include safety suggestions
- Creation of a PAWS Tracking System that is available on the Internet
- Creation of Job Safety Assessment (JSA) forms for each of the thirteen traditional experiments.

INTERNET HOMEPAGE

Everyone is encouraged to visit the Unit Operations Laboratory homepage, located at

http://www.chem.mtu.edu/classes/uo/safety/chem.htm

From this page, it is possible to obtain Material Data Safety Sheets (MSDS) via a link to

http://www.pdc.cornell.edu/issearch/msdssrch.htm

or to obtain more safety information specific to the unit operations course (Safety Inspection Checklist, PAWS form, PAWS Tracking System, and Job Safety Assessment form). In addition there is a link to "Tips for Safe Lifting Practices" and to "Hygienic Practices to Keep in Mind." These materials have been presented by past safety committees and the class decided they should be placed on the Internet as a reminder to help prevent accidents and to promote good hygiene practices.

SAFETY INSPECTION CHECKLIST (SIC)

In the past, the safety committee was responsible for conducting safety audits of the unit operations laboratory. But a formal checklist had not been developed to conduct and record the findings of the audit. Table 1 describes how to complete the SIC, and Table 2 (next page) shows the items listed on the checklist. The actual checklist is designed with a check box for each item for each day of the month.

In order to construct the SIC form, the safety committees studied similar forms from various sources.[3-5] The form is divided into two major sections: the first covers general laboratory items and the second covers safety items related to each individual experiment. The safety committee uses this form at the beginning, during, and at the end of each laboratory period in which experiments are being conducted. Typically, during a month there will be students in the laboratory on six different days.

One SIC form is used for an entire month and is posted by the unit operations laboratory office, and at the end of the month it is filed in the office. If a safety problem is noticed while they are conducting the inspection, the committee attempts to take immediate action to remedy the problem.

TABLE 1
Safety Inspection Checklist (SIC)

The Safety Inspection Checklist was developed to provide the Safety Committee, the faculty, and staff with an organized and effective means for inspecting the Unit Operations Laboratory. It also provides a record of what has been inspected in the past. The inspection is done to ensure that the lab operates in the safest manner possible, that all equipment in the UO Lab is in proper working condition, and to detect and correct any deficiencies in the lab.

How to Complete the SIC

- The SIC is divided into two categories: Unit Operations Area and Individual Experiments. The Unit Operations Area of the check list covers items that are not assigned to an individual experiment, such as fire extinguishers, safety showers, ladders, etc, while the Individual Experiments section involves equipment and hazards associated with one particular experiment and includes such things as guards over pumps, gloves worn for changing a die, etc.

- The Safety Committee will fill out the SIC at the beginning and end of the UO Lab day. The checklist is a month-long document with the days of the month indicated at the top. The month and year that the inspection was performed must be filled out if that item is blank on the document. A box associated with each item on the checklist is split in half so that each item can be checked twice—once at the beginning of the day and again at the end of the day. After completing the inspection, the inspector must initial the bottom of the document under the proper day. Once the two inspections have been completed, the SIC is then posted on the chalk board for future inspections. When the month has been completed, the document should be turned over to Tim Gasperich in the UO Lab office for storage and a new SIC can be obtained on disk from Dr. King.

- If any problems arise while performing the inspection, the group must take immediate action to remedy them. If additional assistance is required, the group must inform the appropriate personnel. If there is any equipment missing, a PAWS form should be filled out, and if a safety hazard is noted during the inspection, a PAWS form should be completed and the safety hazard should be corrected as soon as possible.

- *Go to SIC form.*

TABLE 2
Safety Inspection Checklist

UNIT OPERATIONS

Emergency Procedures
- Evacuation routes posted
- All exits and fire doors clearly marked and unobstructed
- Telephones accessible and labeled with emergency numbers
- Eyewash and safety showers clearly marked and unobstructed
- Eyewash inspection up to date with tag
- Safety shower inspection up to date with tag
- Water continued to flow when handle was released
- Eyewash flushed out
- Safety shower flushed out

First Aid
- Adequate supplies stocked
- Clearly marked and unobstructed

Fire Extinguishers
- Clearly marked and unobstructed
- Inspection up to date with tag
- Correct extinguisher for hazards present

Personal Protective Equipment
- Ankle-high boots worn with proper material
- Long pants worn: No loose clothing, hair, or jewelry
- Appropriate eye wear and properly marked
- Safety goggles worn when handling hazardous chemicals
- Hard hat worn at all times; Earplugs worn in designated areas
- Appropriate gloves worn and available
- Dust masks and respirators in UO lab office

Electrical
- Left-hand rule used
- Power off to make electrical connections
- Extension cords away from traffic and water
- 3-pronged plugs on cords with ground
- Cords without frays or splices
- Make sure the overhead crane is locked and tagged

Chemicals
- Stored in the proper cabinet; Storage cabinets labeled clearly
- Clearly and properly labeled
- Transported properly

Housekeeping
- Counters and floors clean and uncluttered
- Ladders in good condition and chained when not in use
- Cylinders labeled, upright, and secure
- Waste containers provided and labeled
- Make sure drain plugs are present
- Drain is accessible

INDIVIDUAL EXPERIMENTS

Batch filtration
- Agitator locked out when adding slurry to the tank
- Mercury manometer is used
- All valves in proper position when flushing out lines

Continuous Filtration
- All guards are securely in place
- Use left-hand rule to turn on power
- Power supply locked out when manually stirring tank

Continuous Stirred Tank Reactors
- Cart wheels are kept blocked
- Agitator immersed in solution when starting and stopping
- Valves closed when starting reaction

Cooling Tower
- Guard on blower securely in place
- Ear plugs worn for noise level
- Liquid water flowing to heater before starting steam flow
- Steam valve closed before liquid water valve

Flow Measurement
- Mercury manometer is used
- Pump guards properly secured
- Vent and drain lines before changing orifice

Fluidization
- Dust mask worn when screening sand
- Ear plugs worn when using Ro-Tap
- Open valve on air supply slowly

Heat Transfer
- Insulated gloves worn when operating steam valves
- Opened steam valves slowly
- Electric timers are away from water
- Stayed clear of steam traps and heater

Liquid-Liquid Extraction
- Protective gloves, apron, and goggles worn to handle acetic acid
- Kerosene samples poured back into kerosene barrel after use
- Kerosene pump guard in place
- Sampling valves closed after samples taken

PDMS Bench-Scale Reactor
- Goggles, rubber apron, and rubber gloves used to handle KOH
- Red safety can used to weigh and transfer endblock A, 245 fluid
- Pipes and hoses are in good condition and connections are tight
- System inerted with nitrogen at all times
- Experiment run in the hood
- Main gas cylinder valve fully open
- Glassware and thermometer transferred in proper container

Solvent Recovery
- Gloves to be worn during sampling
- Take precautions during sampling (i.e., dripping after sampling)
- Check position of valves

PDMS Jacketed Reactor
- Goggles, rubber apron, and rubber gloves used to handle KOH
- Red safety can used to weigh and transfer endblock A, 245 fluid
- Pipes and hoses are in good condition and connections are tight
- System inerted with nitrogen at all times
- Main gas cylinder valve fully open
- Glassware and thermometer transferred in proper container
- Face shield worn when adding chemicals to reactor

Polymer Flow
- Guards in place and properly installed
- Capillary viscometer pressure no greater than 20 psig
- Tanks not overfilled

Polymer Processing
- Insulated gloves worn when changing dies;
- Gloves to be worn during sampling
- Dies fastened correctly
- Heating wires properly attached
- Proper tools used for scraping polymer

Pumping A
- Pump guards are in place and properly secured
- Shut down procedure executed properly

Pumping B
- Pump guards are in place and properly secured
- Shut down procedure executed properly

Distillation-Solvent Recovery
- System inerted with nitrogen at all times

Vacuum Drying
- Vacuum pump guard properly secured
- Insulated gloves used to operate steam valves
- Dust mask worn when screening sand
- Ear plugs worn when using Ro-Tap

When it is not possible to remedy the problem immediately, the committee fills out a PAWS form so there will be a record.

REVISED PAWS FORMS

The Prevent Accidents with Safety (PAWS) program, initiated at MTU in 1989, is designed to actively and positively involve the students in the safety program. The unit operations students are responsible for their own safety as well as the safety of others working in the area, and any student observing an unsafe act is expected to correct the action before an accident occurs. After correcting the unsafe act, the student completes a PAWS form, which mentions the group that corrected the unsafe act. PAWS points are awarded (positive for safe acts, negative for unsafe acts), and the group with the most PAWS points each quarter is rewarded with a dinner hosted by the developer of the PAWS program, Dr. A. J. Pintar. Submissions of a "nitpicking" nature are discouraged by not assigning them any points. In a typical cycle, approximately twenty PAWS forms are submitted. Most of them concern personal protective equipment, improper handling of chemicals, and equipment problems. Most PAWS forms are submitted by groups other than the safety committee.

My industrial experience has taught me that people often have good ideas for improving safety, so the PAWS form was modified to encourage students to develop ways for improving safety in the lab as well as to report unsafe acts. In addition, students developed a checklist for common safety concerns. Table 3 describes how to fill out the PAWS form, and Table 4 displays a blank PAWS form.

I also encouraged the safety committees to develop a PAWS Tracking System that could be used to track the forms that were submitted. This system was placed on the Internet so students could view the action that had been taken on their item, could prepare for their next experiment by studying past safety mistakes or concerns observed by

TABLE 3
Filling Out a PAWS Form

***Part 1* (Situation Observed)**

1. A situation is observed in the lab that needs to be reported. If you are making a safety suggestion, skip to Part 2.
2. Obtain a PAWS form from the safety committee, Unit Operations Lab Homepage, or the folder located in the Unit Operations Lab Office.
3. Check the line on the PAWS form that describes the situation observed. If none of the lines apply, check "Other."
4. Make additional comments about the situation in the "Comments" section of the PAWS form. Be sure to include what happened, where it happened, how it happened, and if reporting equipment problems, tell what equipment needs to be fixed. Do not include the name of the person who violated safety procedures; this is not what PAWS forms are for.

***Part 2* (Action Taken/Safety Suggestion)**

1. Report what action, if any, was taken to remedy the safety situation or to record safety suggestions in the "Action Taken/Safety Suggestion" section of the PAWS form. Make sure to record which experiment the suggestion applies to.
2. Sign and date the PAWS form. Include your group number on the form.
3. Place the PAWS form in the box labeled "PAWS Forms" located in the Unit Operations Lab office.

Safety Committee Duties

1. Make sure that there are enough PAWS forms for the lab day.
2. Supply each lab group with PAWS forms at the beginning of the lab day. Have more ready in case they are needed.
3. Collect PAWS forms from the box at the end of the lab day.
4. Review PAWS forms.
5. Input PAWS forms into PAWS tracking system.
6. Once the lab cycle is completed and the PAWS forms have been entered into the PAWS Tracking system, give the forms to Dr. Pintar.

Go to PAWS form.

TABLE 4
PAWS Form

PAWS
Prevent Accidents With Safety
Unsafe Situation Report Form

Situation Observed
___ Improper protection equipment (hard hat, safety glasses, boots)
___ Didn't use goggles while transporting chemicals
___ One person moving ladder over 6 feet tall
___ Transporting glassware without bucket
___ Equipment left unattended
___ Equipment problem
___ Other

***Comments* (where, how, what, experiment name)**
_____
_____
_____
_____
_____
_____

Action Taken / Safety Suggestion
_____
_____
_____
_____
_____
_____

Signed _____
Lab Group _____ Date _____

previous groups, etc.

Table 5 shows the PAWS Tracking System items submitted (first page only) for cycle 3 of the 1996-97 academic year. These items include unsafe acts, safety suggestions, equipment problems, etc., related to each experiment. The form also lists who is responsible for remedying the problem and if the item is open or closed ("open" meaning action is still needed and "closed" meaning action has been taken and the item resolved). Open items are discussed with the students, faculty, and staff at the required safety meeting for each laboratory cycle. Each safety committee is responsible for making progress toward "closing" the remaining "open" items.

JOB SAFETY ASSESSMENT (JSA) FORMS

JSA forms are often used in industry and are typically completed for each "job" conducted in an industrial laboratory. They list each step in the procedure, the potential hazards of each step, the recommended safe procedure to use for each step, and the required personal-protection equipment. Using them as a model, I encouraged the safety committees to develop a JSA form to use for our thirteen traditional unit operations experiments. Table 6 describes how to complete the form and Table 7 shows a blank JSA form, which also includes a safety awareness section (nearest fire extinguisher, eye wash, etc.) and the emergency shutdown procedure.

In the 1996-97 academic year, the safety committees and the groups conducting the experiment believed that the JSA form was useful to complete, could prevent accidents, and should be implemented as a required procedure. Thus, in the 1997-98 academic year, each unit operations group conducting one of the thirteen traditional unit operations experiments had to independently complete a JSA form for their experiment prior to running the equipment. The students do not have access to the JSA forms completed for the experiments in the previous year, but the faculty advisor for each experiment uses a completed JSA form as a guide for evaluating the group's JSA form.

SUMMARY

Student involvement in safety procedures prevents the need for faculty/staff-mandated safety rules. The students enjoyed working on these safety enhancements to the unit operations course. They were enthusiastic about the projects, they produced high-quality products, safety in our unit operations course has been improved, and our students are better prepared to work in industry as a result of these procedures.

ACKNOWLEDGMENTS

I would like to thank the entire 1996-97 unit operations class for their participation in the project. I would also like to

TABLE 5
PAWS Tracking System

PAWS INFORMATION FOR EXPERIMENT
Cycle 3

Item #	Group #	Experiment Name	Date PAWS form filled out	Unsafe Act/Situation/ Suggestion	Action Taken	Person Responsible	Open/ Closed	Comments
69	1A	Safety	10/1/96	Open electrical conduit connection on electrical box for heating oven.	Tim Gasperich was informed and he fixed the electrical box.	TPG	Closed	
70	8B	Heat Transfer	10/3/96	Leaky drum for heat exchanger - red gate valve on drum - rusted on bottom near valve created very wet floor.	Labeled and set aside drum, cleaned up floor. Tim Gasperich was informed and he fixed the drum.	TPG	Closed	
71	Dr. Pintar	Safety	12/3/96	Ladders left unchained overnight.	Put chain around ladders.	AJP	Closed	
72	11A	Liquid-Liquid Extraction	12/5/96	Found broken, dirty glassware on floor by liquid-liquid extractor.	Picked up and put in broken-glass container.		Closed	
73	11A	Liquid-Liquid Extraction	12/5/96	Worn sticker on liquid-liquid extractor. H.F.& R. of raffinate stream unreadable.	Sticker replaced and numbers filled in according to kerosene specs. (Traced pipes to kerosene tanks.)	TPG	Closed	

TABLE 6
How to Fill Out a JSA Form

Job Safety Assessments (JSA)

Introduction to Job Safety

The Job Safety Assessment (JSA) Form provides a faster way of identifying potential hazards in the Unit Operations Laboratory. It acts as a useful reference displaying possible hazards that can occur in each step in an experiment.

Format of Finalized JSA

The **first section** is used for identifying each experiment, including the name of the process. Space is provided for the person responsible for filling out the original JSA form. Experimental procedure for a process may change and this could cause a change in the safety hazards associated with that experiment, making revisions necessary. There is a space provided for the person making these revisions, as well as a revision number, revision date, and revision approval by the appropriate faculty. Either Dr. Ellis or David Caspary are the designated persons to approve the revised JSA. Also, the first section contains a portion that shows the necessary personal protective equipment required for the lab. In most experiments, all equipment listed on this form (hard hat, safety glasses, ankle-high books, long pants) are required, but there are exceptions for some experiments.

The **second section** is divided into four columns. The first column contains a detailed sequence of the steps in an experiment, including startup, run time, and shutdown. Potential hazards that can occur at each step of the procedure are listed in the second column. The recommended procedure to prevent these hazards is listed in the third column, and personal protective equipment required for a step is listed in the fourth column.

The **last section** contains the location of safety devices nearest the experiment as well as an emergency shutdown procedure. The safety devices include the nearest fire extinguisher, emergency eye wash and shower, emergency exit, first-aid kit, drain, and telephone.

Go to JSA Form

TABLE 7
Blank Job Safety Assessment Form

Job Safety Assessment Form		Unit Operations Laboratory Department of Chemical Engineering Michigan Technological University	
Process Name:	Hazard Level (high medium, low)	Written by:	
		Revised by:	Revision #:
Process Location		Revision date:	Revision approved by:

Required Items for Lab:
Hard Hat | Safety Glasses | Ankle-High Boots | Long Pants

	Sequence of Steps	Potential Hazards	Recommended Safety Procedure	Required Personal Protective Equipment
Startup				
Run Time				
Shutdown				

Safety Awareness:
Nearest Fire Extinguisher _____
Nearest Eye Wash & Shower _____
Nearest Emergency Exit _____
Nearest First-Aid Kit _____
Nearest Drain Plug _____
Nearest Telephone _____

Emergency Shutdown Procedure
_____
_____
_____

thank Dr. Anton J. Pintar, Dr. Daniel A. Crowl, Dr. Thomas G. Ellis, Mr. David W. Caspary, and Mr. Tim P. Gasperich for their advice.

REFERENCES

1. Pintar, A.J., D.W. Hubbard, and D.A. Crowl, "Teaching Process Safety to Undergraduate Chemical Engineering Students," AIChE 1993 Annual Meeting, Symposium on Integration of Safety and Process Design in Chemical Engineering Education, St. Louis, Missouri, November 9, 1993
2. Pintar, A.J., "Safety Manual for Use in the Chemical Engineering Unit Operations Laboratory," Department of Chemical Engineering, Michigan Technological University, Houghton, MI 49931, August 1996
3. *Laboratory Safety Evaluation Checklist*, University of Texas at Austin, Office of Environmental Health and Safety, Hazardous Materials Division (1996)
4. Maertens, J., *Safety in Chemical Engineering Research and Development,* VCH Publishers Inc., New York, NY (1991)
5. *Guidelines for Incorporating Safety and Health into Engineering Curricula: Vol. 1. Laboratory Safety,* Joint Council for Health, Safety, and Environmental Education of Professionals, Savoy, Illinois (1994) ❐