CAPSTONE CHEMICAL ENGINEERING LABORATORY COURSES AT MICHIGAN TECH

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ABSTRACT

After a switch from quarters to semesters in academic year 2000-01, chemical engineering students at Michigan Technological University (MTU) are required to take two one-semester capstone chemical engineering laboratory courses: Unit Operations Laboratory and Plant Operations Laboratory. In many ways the Unit Operations Laboratory course would be considered traditional. However, there are some features that make it unique. The Plant Operations Laboratory course is built around the MTU Process Simulation and Control Center (PSCC) and is a new course that was developed in conjunction with the switch to semesters.

The objectives of the Unit Operations Laboratory course are to develop (1) a constant awareness of safety in the laboratory; (2) the ability to plan and carry out experimental investigations of large-scale processes; (3) the ability to obtain the experimental data required by the experimental plan; (4) competency in analyzing experimental data; (5) the ability to report the results of the experiment in a concise; well written, well documented technical report; (6) the ability to present the results in a professional, oral presentation; (7) the ability to work in a team; (8) confidence through the application of previously acquired knowledge; and (9) an ability to use software tools typically used by Chemical Engineering professionals.

The students work in self-selected groups of three or four. Each group performs three unit operations experiments, which operate on a four week cycle: one week for planning, two weeks for experimentation, and one week for oral presentations and report writing. The students develop their own operating procedure for running the experiment. The procedure and safety considerations are combined into a Job Safety Assessment Form (JSA).

A safety program, initiated in 1982, has evolved into an extensive safety program, PAWS (Prevent Accidents With Safety), with a high level of student involvement. During each experimental cycle, a group is designated to serve as the student Safety Committee as its assigned experiment. Among other duties, the Safety Committee conducts safety audits of the unit

operations laboratory using a Safety Inspection Checklist (SIC) and conducts the Safety Meeting for that cycle.

The Plant Operations Laboratory course focuses on process operations, management, and statistical process control. The student groups from the Unit Operations Laboratory are combined into teams with two groups per team. Each team operates the two highly automated PSCC processes (batch polymerization reactor and solvent recovery unit) and a bioreactor/bioseparation process. The length of the runs requires the students to work in shifts. The student teams are given production targets to achieve.

INTRODUCTION

A full-year capstone laboratory course, Unit Operations Laboratory, has been required for a Bachelor of Science Degree in Chemical Engineering at Michigan Technological University since the early 1940's. Over the years the experiments have changed and the course requirements have evolved. A special emphasis on safety was introduced in 1982 (Crowl, Pintar, *et al*., 1994; Hubbard, Pintar, and Crowl, 1994; Pintar, 1999; Pintar, King, and Crowl, 1998; Pintar, 1998; Pintar, 1985; Pintar, 1983; and Pintar, Hubbard, and Crowl, 1993). In the early 1990's the Process Simulation and Control Center (PSCC) was developed and incorporated into the Unit Operations Laboratory course (Pintar, Caspary, *et al*., 1998).

In academic year 2000-01 Michigan Tech officially switched to a semester system. In preparing for this switch, the capstone laboratory course was changed to a one-semester Unit Operations Laboratory course and a one-semester Plant Operations Laboratory course. The Unit Operations Laboratory course may be considered traditional, but there are some features that make it unique. The Plant Operations Laboratory course is built around the MTU PSCC.

CHEMICAL ENGINEERING UNIT OPERATIONS LABORATORY

The Unit Operations Laboratory course is taken during the Fall Semester of the senior year. At the beginning of the semester the students receive the Course Handbook and Syllabus (Michigan Tech, September 2000) and the Safety Manual (Pintar, 2000). Copies are available upon request.

Course Objectives

The course objectives are given in the Handbook and Syllabus:

1. Develop a constant awareness of safety in the laboratory so that all laboratory work is carried out in a safe manner.
2. Develop the ability to carry out experimental investigations of large-scale processes including:
   The ability to develop equipment diagrams and comprehensive safe operating procedures for various unit operations.
   The ability to develop a specific experimental plan when given a vague set of objectives.
   The ability to obtain the experimental data required by the experimental plan.
3. Competency in analyzing experimental data and in comparing the results to data and theories from the literature.

4. The ability to report the results of the experiment in a concise, well written, well documented technical report.
5. The ability to present the results in a professional, oral presentation using available technological resources.
6. Develop the ability to work in a team by:
   Actively participating as a member of a professional group.
   Supervising a peer group of professional chemical engineers.
   Managing conflicts within the team as they arise.
7. Develop confidence through the application of previously acquired knowledge of unit operations, chemical reactions, process safety, and process control.
8. Learn to use software tools typically used by Chemical Engineering professionals.

All of the course activities are geared towards meeting these objectives.

Course Structure

The course meets one day per week in two sections from 8 a. m. to 5 p. m. The 8–9 a. m. time slot is normally used for lectures and for the Safety Meetings. Lecture topics include details on the laboratory proposal and on the final report, presentation of sample calculations, and error analysis. There typically are 90-100 students in the course. Three faculty members supervise the experiments with one serving as the course coordinator. Two graduate teaching assistants and a laboratory technician oversee the laboratory. The students work in self-selected groups of three or four. Each group performs three unit operations experiments from the following list:

Fluid Mechanics
Continuous Filtration
Flow Measurement
Fluidization
Non-Newtonian Flow
Pumping A
Pumping B

Heat Transfer
Shell-Tube Heat Exchanger
Single-Pass Heat Exchanger
Vacuum Drying

Mass Transfer
Cooling Tower
Liquid-Liquid Extraction

Reactions
Stirred-Tank Reactor

Miscellaneous
Safety

Each group performs at least one flow experiment and at least one experiment from the other categories. The students are asked for any preferences they have for their assigned experiments. Generally, they get at least their first choice and in most cases all of their choices.

The first two weeks of the semester are devoted to course orientation and to safety training. The remainder of the semester is broken into three experimental cycles that follow this basic schedule:

Week 1	Obtain objectives from faculty adviser Develop plan for the experiment Prepare laboratory proposal and submit portfolio to faculty advisor Check-in meeting with faculty advisor
Week 2	Run experiment in the laboratory Calculations and data analysis Informal data debriefing
Week 3	Run experiment in the laboratory Calculations and data analysis Informal data debriefing
Week 4	Safety Meeting Oral Presentations Prepare final report and submit portfolio to faculty advisor

The students develop their own operating procedure for running the experiment. The procedure and safety considerations are combined into a Job Safety Assessment Form (JSA). The check-in meeting is used to review the JSA to make sure that the experiment will be carried out correctly and safely.

For educational reasons, the laboratory proposal and final report for the first experiment are submitted by the students to the faculty advisor, reviewed by the faculty advisor and returned to the students with comments but no grade, and then submitted in final form by the students for grading.

The student groups develop a portfolio for each experiment. The portfolio contains all of their work on that experiment: objectives, laboratory proposal, data, transparencies for the oral presentations, group meetings, final report, and peer evaluations.

Safety

The safety program mentioned earlier has evolved into an extensive safety program, PAWS (Prevent Accidents With Safety), with a high level of student involvement. During each experimental cycle, a group is designated to serve as the student Safety Committee as its assigned experiment. Among other duties, the Safety Committee conducts safety audits of the

unit operations laboratory using a Safety Inspection Checklist (SIC) and conducts the Safety Meeting for that cycle. The Safety Meeting serves as the oral presentation for the Safety Committee. The Safety Committee also carries out an assigned safety project and reports on it at the Safety Meeting.

Grading

The group receives a grade for each laboratory proposal, for each oral presentation, for each laboratory report, and for completeness of each portfolio. Individuals receive a grade for their performance at each check-in meeting and for attendance and safety quizzes. There are a total of 800 points: three laboratory proposals/check-ins at 100 points each, three laboratory reports at 100 points each, three oral presentations at 40 points each, three portfolios at 10 points each, and 50 points for attendance and safety quizzes.

CHEMICAL ENGINEERING PLANT OPERATIONS LABORATORY

The Plant Operations Laboratory is taken during the Spring Semester of the senior year with Spring 2001 being the first time this course has been offered. The purpose of the course is to provide first-hand experience in process operations, process management, and process safety. The course emphasizes quality operations and incorporates statistical process analysis to evaluate and optimize operations. Industrial speakers and faculty from the School of Business and Economics provide lectures on statistical process control and Six Sigma methodologies.

Course Structure

The student groups from the Unit Operations Laboratory are combined into teams with two groups per team. Each team has a self-chosen leader and a safety officer. The leader is responsible for process management oversight for the run and the safety officer is responsible for ensuring that safety is included in all activities. Each team operates the two highly automated pilot plant facilities of the PSCC (a 20 gal. PDMS batch polymerization reactor and a 30' solvent recovery unit) and a bioreactor/bioseparation process. The length of the pilot plant runs necessitates the students working in shifts. The shift work is scheduled by the team around a standard operating procedure (SOP). Each team is given a production target to achieve and is required to review past run materials to assure familiarity with past performance. It is the intent of the course to use statistical methods to continually improve operations toward the production target. The bioprocess teams are formed by combining a Tuesday and Thursday section group. The Tuesday group starts the run and the Thursday group completes the run.

Due to the number of students in the course (96) and the availability of pilot plant facilities a staggered schedule is used. Each process cycle is operated on the following schedule:

Week 1 Orientation to the process, obtain team/group objectives from faculty advisor. Identify team leader and safety officer.

Week 2 Develop a detailed plan to operate the process following the SOP. Prepare Pre-Laboratory Proposal and submit as part of the portfolio for approval. Check-in meeting with faculty advisor authorizes the run.

Week 3 Run the pilot plant facility (typical run time is 10-12 hours), perform calculations and data analysis, meet with faculty advisor for informal data debriefing.

Week 4 Formal Oral Presentations, prepare Final Report and submit portfolio to faculty advisor for grading.

Safety

Each process cycle features a Safety Meeting managed by the safety officers of each team. This Meeting reviews all active PAWS forms from laboratory operations and introduces a separate topic for safety discussion by the students. Attendance at the Safety Meeting is mandatory.

Grading

The course is graded by teams with 240 points maximum per process cycle: 100 points maximum for the Pre-Laboratory Proposal and Check-in, 40 points maximum for the Oral Presentation, and 100 points maximum for the Final Report.

FUTURE PLANS

As a part of the switch to semesters, a junior-year Chemical Engineering Laboratory course was introduced into the curriculum. Some of the experiments in the Unit Operations Laboratory are now covered in the junior year (pipe flow, flow measurement, and single-pass heat transfer). Some of these experiments will be eliminated from the senior-year Unit Operations Laboratory course and new experiments will be introduced. Membrane separation, gas absorption in a packed column, and distillation in a plate column are among those being considered.

A third pilot plant facility for the PSCC is in the planning phase. This facility will feature a crystallization and solids recovery process designed around the pharmaceutical industry. When this facility is completed it will be integrated into the Plant Operations Laboratory.

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BIOGRAPHICAL INFORMATION

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Professor of Chemical Engineering at Michigan Technological University, recently stepped down as department chair after twelve years. B. Sc. in ChE from the University of California-Berkeley and a Ph. D. in ChE from Johns Hopkins University. He was a faculty member and associate dean of engineering at Wayne State University before joining Michigan Tech. Actively involved with the unit operations laboratory and the PSCC facilities.

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