Minimizing Environmental Impact of Chemical Manufacturing Processes[1]

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Introduction

Knowledge of technologies and strategies for pollution prevention and the remediation of hazardous pollutants, as well as the environmental impact of pollutants that are released into the environment, is an increasingly important part of the average Chemical Engineer's job responsibilities. Therefore, in the Departments of Chemical Engineering at the University of Notre Dame, West Virginia University and the University of Nevada at Reno, we are implementing through courseware, research, and design projects a program to

1. develop the students' appreciation of the impact of pollutant release from chemical processes and of the environmental, ecological, and long-term economic benefits of pollutant minimization or elimination,

2. equip them with active knowledge of the technology that is being developed for minimizing the environmental impact of chemical manufacturing processes,

3. show students how this new technology can be implemented.

The overall goal of this project is to incorporate the results of recent and ongoing research taking place at the three participating institutions, as well as elsewhere, on environmentally conscious chemical manufacturing processes into the chemical and metallurgical engineering curricula. This research includes pollution prevention, waste reduction, environmentally conscious chemical process design, and the modeling and assessment of the environmental and ecological impact of pollutant release.

The overall program includes the incorporation of research results into instructional modules that can be integrated throughout the chemical engineering curriculum, with a special emphasis on the design sequence. These modules include:

1. the development of two new courses:

    a. Environmentally Conscious Chemical Process Design (Pollution Prevention)
    b. Ecology and the Environment

2. the development of environmentally related design projects

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3. the development of environmentally related companion course materials.

Information on the entire project can be found at: http://www.nd.edu/~enviro. Design project statements and companion course materials can be downloaded, and course materials can be viewed.

In this paper, the two new courses listed above will be discussed in more detail.

Course on Ecology and the Environment

Upon completing an undergraduate chemical engineering curriculum, the typical student has grasped a large set of fundamental concepts, and he or she can apply them, more or less adeptly, to the understanding, analysis, and design of processes. Increasingly, such students are made aware that engineers must assess and be accountable for the environmental impact of their designs. Nevertheless, many graduating chemical engineering students have little more than a layman's understanding of the workings of the natural world and of the consequences of human/industrial disturbances – even though the same fundamental concepts underlie both the natural and man-made processes.

The objective of this course is to give the students an appreciation, in a technical sense and from a chemical engineering perspective, for the dynamics of processes in biotic and abiotic systems outside the boundaries of the industrial plant. This is accomplished by applying material and energy balances, the laws of transport and chemical change, and mathematical methods to various topics on ecology and the environment. In addition to regular lectures and assignments, components of the course include group projects and presentations. A brief list of course topics and example projects is given below. The common centerpieces are mathematical model formulation and computer simulations.

The course was offered for the first time in the spring semester of 1999 at the University of Notre Dame. The syllabus is shown in Table 1. Twenty-eight students, all chemical engineering seniors, were enrolled. Informal feedback from the first offering indicated that the course was well received by the students, and that the subject matter gave the students a greater awareness and appreciation for environmental matters – and of the general applicability of their chemical engineering background. Students particularly seemed to enjoy working on projects that have a twist different from what they usually encounter in their courses – and that were familiar to them beforehand mainly through the popular press. The course will be offered for the second time in the spring semester of 2000, when all of these perceptions will be tested on a firmer basis through formal and systematic student evaluations. More details will be available in the presentation at the meeting.

Course in Pollution Prevention

This course was taught at the University of Notre Dame with the title "Environmentally Conscious Chemical Process Design" in Spring 1997, Spring 1998 and Fall 1999. A similar course entitled "Pollution Prevention" will have been taught at West Virginia University in Spring 2000. The latter class will be based, in part, on a draft of the "Green Engineering"

Table 1: Syllabus for Course on Ecology and the Environment

Introduction -- description and overview of the Earth's interacting biotic and abiotic subsystems

Biota Dynamics -- dynamics of interacting populations, with emphasis on mathematical models and analysis, effects of parameters and disturbances

Miniproject -- students worked in small groups over a two-week period on projects involving the dynamics of a food web

The Earth's natural and altered environments, including models of

- ozone dynamics in the troposphere and stratosphere
- the Earth's major biogeochemical cycles, with emphasis on the carbon cycle

Course project -- students worked in small groups over a three-week period on projects involving the modeling and analysis of a problem or subject of interest related to the environment. Projects were reported orally to the entire class, and written reports were due at semester's end. Project topics included:

Greenhouse gases and global warming
Ozone dynamics in the troposphere and stratosphere
Lake dynamics and eutrophication
Water acidification by acid rain
The transport and fate of toxic organic pollutants and trace metals
Contamination and methane generation from landfills
The design of Biosphere 2

textbook commissioned by the Environmental Protection Agency that was the subject of a workshop at the 1999 ASEE meeting in Charlotte, NC.

The objectives of the course at the University of Notre Dame are:

1. to educate students on the real costs of operating processes that release pollutants to the environment,

2. to provide them with strategies to minimize or reduce the environmental impact of a given chemical process,

3. to examine the design of processes using new technologies that totally eliminate pollutants at the source.

The course includes four major components:

1. an introduction to the idea of waste elimination or reduction, and how pollution prevention differs from remediation. This introduction includes a discussion of waste inventories, life-cycle analysis and industrial ecology. An excellent source for this material is the book by Allen and Rosselot.[1]

2. a discussion of the pertinent environmental regulations that impact the design and operating costs of chemical processes. A nicely condensed version of these laws is available from the National Pollution Prevention Center.[2]

3. a survey of current research efforts to develop alternative technologies that minimize waste or eliminate pollutants.

4. examination of a series of case studies that compare designs of conventional chemical processes to those using new, environmentally benign, technologies.

This course provides practical information, as well as exposure to the new technologies that are currently being developed for pollution prevention. With this course, the goal is for our graduates to become chemical engineering professionals who are equipped with the awareness, knowledge, and ability to minimize the environmental impact of the chemical manufacturing processes that they oversee.

Students were given a questionnaire to complete upon entrance and upon completion of the course. At this time, results are only available for the Spring 1997 and Spring 1998 course offerings. These results are summarized in Table 2.

Table 2: Partial Results of Entrance and Exit Questionnaire for Pollution Prevention Class at the University of Notre Dame

Question and Response Scale (where applicable, correct answer in bold)	Spring 1997		Spring 1998	
	before	after	before	after
The U.S. is being put at a competitive disadvantage in the global marketplace due to environmental regulations, which are much more stringent here than elsewhere in the world. (Responses on 1-5 scale, 1 = strongly agree, 5 = strongly disagree)	2.95	3.36	3.75	3.29
Making changes in chemical processes to reduce or eliminate the release of pollutants is too expensive. (Responses on 1-5 scale, 1 = strongly agree, 5 = strongly disagree)	3.74	4.15	3.93	3.76
Accidental release of pollutants from chemical processes is inevitable. (Responses on 1-5 scale, 1 = strongly agree, 5 = strongly disagree)	3.63	3.20	3.14	3.12
Relative to other prominent issues, such as the economy, welfare reform, crime, etc., how would you rank pollution emitted from chemical manufacturing processes as an important issue? (Responses on 1-4 scale, 1 = not important at all, 2 = somewhat important, 3 = important, 4 = very important)	3.32	3.13	3.28	3.12

Table 2: Partial Results of Entrance and Exit Questionnaire for Pollution Prevention Class at the University of Notre Dame (continued)				
How are most pollutants from chemical manufacturing facilities released to the environment? (circle one) (% correct shown) **air** water soil	84	77	76	63
Currently, what is the incident rate (the number of fatalities per 10,000 workers) for all industry sectors in the United States? (circle one) (% correct shown) 0.1 **1** 10 100	26	29	45	62
Information on toxic releases is (circle one) (% correct shown): a) classified for national security reasons, b) available from the EPA if you can demonstrate need-to-know, c) available to anyone via the freedom of information act, or **d) available to anyone on the internet.**	11	93	29	82
The number of chemicals and chemical categories currently reported in the Toxic Chemical Release Inventory is about __? (circle one) (% correct shown): 10 75 300 **600** 3000	26	64	31	76
The Clean Air Act establishes National Ambient Air Quality Standards (NAAQSs) for six "criteria pollutants." Name as many as you can. (# correct shown): **NO_x, SO_x, CO, lead, ozone, particulates**	2.26	4.93	1.48	5.97
What manufacturing sector is the major contributor to pollution in the US? (% correct shown): **chemicals/petrochemicals**	63	86	41	62
Major legislative initiatives to improve environmental quality began in what decade? (% correct shown): **1970s**	21	53	48	79

The results in Table 2 suggest that the course at the University of Notre Dame has been successful in increasing students' knowledge about environmental regulations and pollutants. There are other items on the questionnaire that require explanations that are not amenable to numerical representation, and the responses are consistent with an increased knowledge about pollution prevention. However, based on the first four questions, there appears to be no systematic change in student attitudes. Results from similar questionnaires for the Fall 1999 course at the University of Notre Dame and for the Spring 2000 course at West Virginia University will be presented at the meeting.

Conclusion

A program has been described that incorporates research results on pollution prevention into the undergraduate curriculum. Two new courses have been described, one on Ecology and the Environment and one on Pollution Prevention. The latter has been taught several times at two universities. Evidence suggests that the course has been successful. Projects on environmentally conscious process design and companion problems for the curriculum have also been developed, and these materials are available for the public on the project web site http://www.nd.edu/~enviro.

Bibliography

1. Allen, D. T., and K. S. Rosselot, *Pollution Prevention for Chemical Processes*, Wiley-Interscience, New York, 1997.
2. Lynch, H., *A Chemical Engineer's Guide to Environmental Law and Regulation*, available from the National Pollution Prevention Center for Higher Education (nppc@umich.edu).

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