CHEMICAL PROCESS DESIGN*
An Integrated Teaching Approach

KENNETH A. DEBELAK AND JOHN A. ROTH
Vanderbilt University
Nashville, Tennessee 37235

THE EFFECTIVE TEACHING OF design to chemical engineering seniors often presents a challenge for many chemical engineering faculties. Philosophically, the senior design project should integrate flow sheet generation, chemical engineering sciences, transport and reaction equipment design skills, and engineering economics. The problem should be structured to emphasize group problem solving, project organization and planning, and effective communications. Further, the problem should be an "as realistic as possible" industrial design problem requiring synthesis of a final process. One way to create an appropriate environment is by combining the design and laboratory courses, thereby relating the design project to real facts, real chemicals, real alternatives, and involving industrial practitioners.

For the past several years we have conducted our senior plant design course as a combined one semester five hour design/laboratory course. Typical design projects have included:

- **polymerization of DMT to polyester [1]**
- **manufacture of acetic anhydride from acetic acid**
- **design of a yeast plant**
- **design of a coking wastewater treatment plant**

These projects have been carried out with the aid of engineers in industry.

In the early stages of the design course/laboratory development, real problems were encountered with obtaining the necessary commitment from industry. The proprietary information hurdles were almost insurmountable. Many projects involved hazardous chemicals and hazardous processes. They also quickly involved considerable expense both for chemicals and experimental equipment. We have found that the use of an energy or environmental design problem provides a solution to many of these difficulties.

John A. Roth is a Professor of Chemical and Environmental Engineering at Vanderbilt University. He received his education at the University of Louisville (B.ChE., 1956; M.Ch.E., 1957; Ph.D., 1961). He has had experience in industry and government, both full-time and as a consultant in the environmental area. His research interests are in Chemical reactor kinetics and physical chemical waste water treatment. **(L)**

Kenneth A. Debelak is an Assistant Professor of Chemical Engineering at Vanderbilt University. He received his B.S. (1969) in Chemical Engineering from the University of Dayton and M.S. (1973) and Ph.D. (1977) from the University of Kentucky. He has had industrial experience with General Motors and governmental experience with the Environmental Protection Agency. His research interests are in coal kinetics, process control and synthesis, and physical-chemical processes for industrial waste water treatment. **(R)**

COURSE STRUCTURE

THE STUDENTS ARE GIVEN THE design problem during the first week of class. They are assigned to individually synthesize a process to achieve the design objective. The class as a group then decides the process alternatives it wishes to consider in detail. Interaction and limited direction from the course instructors, other faculty,

*A preliminary version of this paper was presented at the 73rd Annual AIChE meeting, November, 1980.

and industrial consultants are essential throughout this process.

The class is organized as a company. A Project Manager and Research Director are nominated by the class and selected by the course instructors. The class is then divided into research/design groups with one member assigned as group leader. These groups develop design methods and cost curves; they also design, execute and conduct experiments to supplement the data and information in the literature. Since some students take only the three hour design course (non-chemical engineering graduate students and selected senior project students), they participate only in development of the design methods and cost information but not the laboratory.

A portion of the classroom time is devoted to a series of formal lectures on

- cost estimation and engineering economics
- related topics (i.e., corrosion, materials selection, patents, the technical library, statistics)
- supporting technical topics pertaining to the major design problem.

Additional homework assignments are made, primarily using Peters and Timmerhaus [2] as a text. One individual short design problem is assigned. Problems are also assigned covering cost estimations, economics, and statistics. One day a week is reserved for discussion of the major project and dissimination of data. Outside speakers are used extensively for the appropriate areas of expertise. The Project Manager, Research Director, and group leaders meet weekly with the course instructors to report on the week's activities and to plan for the next week. A major design report is required from each design group (3-4 persons). Weekly laboratory reports and a final report are required of the laboratory groups.

THE DESIGN PROBLEM

THE SELECTION OF AN appropriate problem is most crucial. It must be challenging but must also have good chances for successful completion. It must be common enough so that there is literature available and also require experimental work to supplement existing data. To actively involve local industries it must not include proprietary information. In the past this has been a serious problem in enlisting industrial support. Two types of problems seem to overcome many of these difficulties—those concerned with energy or environment. These are topical problems and have been enthusiastically supported by both industry and student involvement.

The choice of an environmental process design requires that the student become familiar with a new area, one which has its own terminology and language but which is based on chemical engineering principles.

For the past two years we have focused on the design of wastewater treatment facilities for coal conversion processes. Industrial assistance from the Chemical Technology Division of Oak Ridge National Laboratory (ORNL) and Alabama By-Products Corporation (ABC) has been obtained. The group at ORNL has been responsible for the design of wastewater treatment facilities for coal gasification processes, while Alabama By-Products Company is a coking operation which has had to meet increasingly stringent discharge requirements from the EPA.

The choice of an environmental process design requires that the student become familiar with a new area, one which has its own terminology and language but which is based on chemical engineering principles. We feel that this is a common experience for graduating chemical engineers since they will be required to learn the specific terminology as they take their places in the specific industries.

DESIGN PROJECT EXAMPLE

THE FOLLOWING IS THE statement of the design of a coking wastewater treatment plant:

• • • •

VANDERBILT ENGINEERING COMPANY
INTEROFFICE MEMO

TO: ChE Project Staff

FROM: Design/Laboratory Instructors

Our firm has been retained as consulting engineers to design a wastewater treatment facility for the Tennessee Coking Company, Cumberland Plant. The attachment shows the coking process and characterization of the raw waste load (influent). You are asked to complete a detailed estimate design for the wastewater treatment facility.

Data not available in the literature or uncertain will be determined in the laboratory. Effluent limitations are to be based on Tennessee standards, assuming that this plant will be constructed on the Cumberland River.

The final formal report is due________________. This report will include cost estimates as well as process design. Attach as an appendix your calculations and the source

of your data. You will be supplied the basis for cost estimation.

• • • •

The chemical engineering faculty were available as consultants. The industrial participants were also available to answer questions. The State Environmental Agency was contacted for technical information on waste treatment processes and for discharge requirements the plant would have to meet. Class lectures were presented as requested by the students on the following: biological waste treatment, liquid extraction, sludge dewatering and disposal, carbon adsorption, equilization, clarifier design. A number of textbooks, EPA documents and manuals, and training manuals were made available from the library or from individual faculty.

Biological waste treatment emerged as the cornerstone of the treatment scheme. One group was assigned to investigate this process. For ammonia removal, air stripping and steam stripping appeared as viable processes. Groups were assigned to each of these processes. The remaining laboratory groups were organized for this project as shown in Fig. 1. Each group was responsible for establishing the appropriate analytical tests. Members from other groups were instructed on the tests by the group that established the procedure.

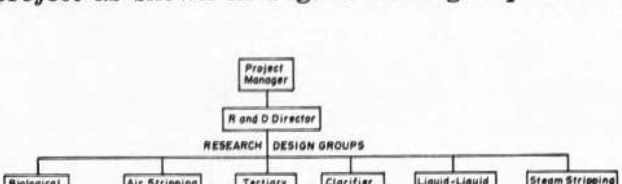

FIGURE 1. Student Organization.

Before entering the laboratory each group submitted a pre-experimental plan outlining their experiments and analytical tests. Also included in the plan was a time-table for completion of the work. These plans were reviewed by the Research Director, Project Director, and instructors. The final laboratory report presented design data and methods and a solved example of a design using design data and equations. A recommendation as to the feasibility of each process was made. Each group also presented an oral report to the entire class. The final reports along with any other information were made available to all class members.

LABORATORY

A SAMPLE OF PROCESS wastewater and sludge was obtained from ABC. Typical laboratory data needs for this project included:

- **rate constants for decomposition of phenol by activated sludge**
- **sludge settling data for clarifier design**
- **neutralization curves**
- **chemical oxidation rates for phenol**
- **carbon adsorption data.**

Bench scale studies were conducted on the activated sludge process in a completely mixed stirred tank reactor (CSTR). Two activated sludge reactors were operated. After flow rates were established for the influent, the process was allowed to reach steady state. Samples were collected over a period of several hours and stored at 0°C until the analyses were made. Kinetics for the removal of Chemical Oxygen Demand (COD), phenol, and cyanide were determined by varying the retention time for each run. Once the reaction rate constants were determined for each pollutant, the retention time for the limiting pollutant could be calculated and the size of the aeration basin determined. The group also determined the amount of excess sludge produced, and made recommendations for oxygen and nutrient requirements. An example of their laboratory data is shown in Fig. 2. This group established analytical procedures for COD, phenol and total cyanides in accordance with Standard Methods. Other groups were instructed in these methods.

The process wastewater obtained from ABC had already been treated to remove ammonia. It was necessary to make a synthetic waste for these experiments. The removal of ammonia by air stripping consisted of the following steps: pH adjustment, air stripping, ammonia adsorption of off gas in dilute sulfuric acid. The last step was then extended to recover the resulting ammonium sulfate, a by-product used for fertilizer. The group determined kinetic data to size the pH adjustment vessel. Mass transfer coefficients were determined for both stripping and absorbing the ammonia.

Not all of the lab groups were totally successful in completion of their assigned tasks. There are numerous reasons for the wide variation in performance among the groups. Some groups had a better understanding of their goals and objectives and better understanding of the processes they were investigating. Some groups just had people who were more motivated and enthusiastic about the project and worked more diligently to achieve their goals. Some of the experimental problems were much more difficult, either because of inherent complexity, lack of equipment, or time constraints when supplies were not readily available.

FINAL DESIGN

THE END PRODUCT OF THE design course is the final report. We have required both individual final reports and 3-4 person group reports. This report is a formal report using the format as recommended by Peters and Timmerhaus [2]. To maintain some measure of uniformity, common economic parameters such as amortization rates, percentage of administrative costs, and other pertinent fixed-capital investment and production costs are specified. Common equipment/process cost curves are used. These are developed by the appropriate laboratory/design groups. There are nevertheless a wide number of options open to the design groups. We have also found that presentation of results by the groups to a joint faculty-industrial audience enhanced interest.

For grading, we heavily weighed peer evaluations for the group laboratory reports and the group design reports.

EVALUATION

FOR THE PAST EIGHT YEARS we have taught our senior design course as an integrated design laboratory course. The students have responded very well to this approach. They perform their work in a mature and professional manner and can see the results of their efforts. This experience forces the students to organize their efforts; make engineering judgments along the way; obtain, find and evaluate data; and organize an experimental program. We feel we have been successful in achieving an atmosphere similar to an industrial situation in which the interaction of a number of groups is necessary for the completion of a project.

We do not wish to gloss over the pitfalls of this approach, for there are several. Advanced planning is necessary. The faculty must develop some feel for the problem since there are an extensive number of student questions and problems which arise. It is important that equipment, reagents, and supplies be on hand before the beginning of the semester. During the first several weeks there is considerable chaos. Students are often unsure of what is expected of them. It is imperative that a timetable be established to keep the project moving forward. We found that a good approach to this problem was to encourage the Project Manager, Research Director, and group leaders to apply group pressure to their peers. Most students accept the challenge and are responsible. It is occasionally possible for a student to slide by with minimum effort. To counteract this, the peer evaluations are quite effective. For the most part, we find the students evaluate each other honestly.

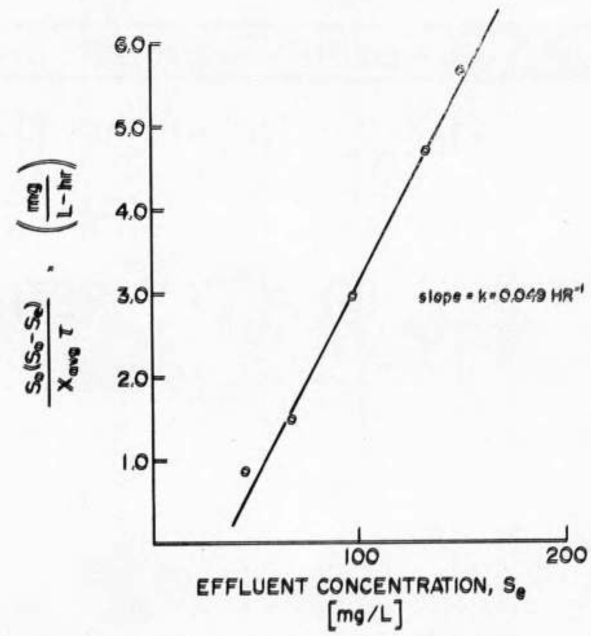

FIGURE 2. Phenol Biodegradability.

This approach to design in the chemical engineering curriculum has been quite effective. We believe it comes close to providing a realistic experience for the student and a professional challenge for the student and the faculty. We heartily endorse this approach for a more effective design experience. □

ACKNOWLEDGMENTS

We would like to thank Jerry Klein, Oak Ridge National Laboratory; John Koon, AWARE, Inc.; and Moyer Edwards and John Shores, Alabama By-Products Corporation, for their time and assistance.

REFERENCES

1. Overholser, K. A., C. C. Woltz, and T. M. Godbold, *Chemical Engineering Education*, 9:16 (1975).
2. Peters, M. S., and K. D. Timmerhaus, *Plant Design and Economics for Chemical Engineers*, McGraw-Hill, Second Edition, New York (1968).