AN OPEN - ENDED COURSE IN CHEMICAL PLANT DESIGN

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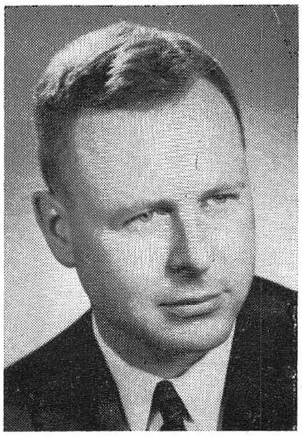
Editors Note: CEE joins the profession in mourning the recent death of Professor O'Connell

Over the years a number of views have been presented on plant design, and each has had its own concept of what design is. Some have concentrated on small problems related to design. Others have concentrated on design calculations. Others have concentrated on the preparation of drawings and specifications. Here at the University of Detroit we have tried to take in the broad concept of design[1, 2], which starts with the conception of a chemical process and ends with the preparation of the drawings and specifications suitable for purchase of equipment and for contractors to make bids on engineering construction. The functions with which the chemical engineer is chiefly interested are emphasized.

CLASS ORGANIZATION

The design sequence consisted of two quarters of ten weeks duration each. In the beginning of the first term a process was assigned, which would consist usually in simply writing a chemical compound, but not necessarily the chemical reaction, for obtaining the compound. The criteria needed for design were worked out during this term. In the second term, then, after the criteria had been worked out through preliminary studies and experimentation, the actual plant design procedure was simulated by the students.

This design sequence was essentially an open-ended course, in that nothing more than a chemical product was assigned to the class. It was a case history approach—the students must decide by what process, chemical reactions, and other modes of procedure that the design should be carried out.



Francis P. O'Connell was at the University of Detroit for many years, where he was Professor of Chemical Engineering. Over the past 30 years he was engaged in research, development, process design, project engineering, plant start-up and operations. A graduate of Villanova University, he had the MS and the PhD degrees in chemical engineering from Lehigh University. Dr. O'Connell was a licensed professional engineer in Pennsylvania and Michigan.

The classes have consisted approximately of twelve to fifteen students who where divided into groups of three to five students each. It is the author's judgment that the optimum group would be somewhere between three and four students. We found that if the group were too small, the students would not be able to cover enough ground to make the assignment worthwhile, and if the group were too large, the more eager students would tend to dominate the group.

DECISION PROCESS IMPORTANT

During the course of this plant design exercise emphasis was not placed solely on calculations, important as they may be. The students had to decide which direction to go, for instance, whether their control valves are to fail open or closed. Here is a list of typical decisions which the students have made:

Whether to use a spray, packed, or plate tower
How much hold-up time for a surge tank
Should reflux be pumped or fed by gravity
Select equipment for separating a liquid-vapor mixture
Should material be shipped by water, road, or rail
Should mounted spare pumps be provided
Mounted spare control valves vs. hand operated by-pass valves

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Can plain carbon steel be used instead of stainless steel
Is an explosion wall necessary
How large should an escape exit be made
Selection of a fire extinguishing system
Selection of nitrogen, helium, argon, or carbon dioxide as an inert gas
Should spring loaded safety valves or rupture discs be used
Method of removing heat from a reactor

It is hoped that engineering judgment and creativity were developed through this decision making exercise. If a student put forward an idea that was half way reasonable, it was never discouraged, but he was encouraged to discuss his idea with others. Synthesis, as well as analysis, of all concepts had to be emphasized.

ENCOURAGING INITIATIVE AND JUDGMENT

One way to encourage this was to have the class assemble about once a week and give a brief written and oral progress report. This was done in the groups in which they were assigned, so that possibly once a week one member of each group would report on the work progress. This gave him a chance to defend his ideas and the ideas of the group against the criticisms of the other groups. And to a certain degree it developed a healthy sense of competition among the groups. We found that this did not tend to make the groups copy one another. Perhaps this is true because right in the beginning of the course the groups selected a particular path to follow as regards such things as reactions and patented processes, and they tended to deviate from one another as time went on. Nevertheless they could exchange ideas with one another, and this was healthy. It is somewhat of an art, trying to develop healthy discussion among the various groups at the weekly meetings. The teacher must not inject himself too much nor too little.

OPTIMUM CHOICE OF PROJECT

One of the more difficult chores of the teacher is to find a suitable process for the students. The following pitfalls stand out in the choice of an assignment:

1. The right amount of data must be available to the students. If there is too little data available in the literature or otherwise, they are forced to do an undue amount of guessing. If there is too much data available, they are unable to digest it in the time allowed, and they tend to copy previous designs. This would be the case with any of the old heavy chemicals, such as sulfuric acid or caustic-chlorine.
2. The number of technological steps should be optimum. Too few steps would lead to a trivial study. Too many steps would render the project too complex for the time allowed.
3. When laboratory investigations are included in the project, the following limitations prevail:
   a. Safety of the students must be assured.
   b. Pick a process which will allow the students to take meaningful data in the time allowed.
   c. Work is limited by laboratory equipment available.
4. The process must be such that it can be run at a suitable capacity. If the capacity is too small, the students will only be designing pilot plants. We try to shoot for about 100 tons per day.
5. Pick a process that is profitable. This is hard to do, and nothing is more discouraging to the students than to find out that their plant will not be able to make money. Unfortunately today most profitable operations have multidepartment plants and multiplant industries, whereas the students are necessarily limited to one process.

PROCESS DEVELOPMENT PHASE

In the first term, or first phase of the program, the students simulated what happens in the process development stage of plant design in industry. This consisted of learning and practicing a number of techniques associated with the problem. The students had to make a market survey to form some idea, at least qualitatively, of what demand could be expected for the proposed product. The first week the groups were given a chance to go over the process, consult literature, and decide with the best judgment they had available at the time which process they wanted to follow through.

This got them started in a given direction, so that they could go through the entire development and design experience. They then developed a rough flow sheet and went into estimation of fixed and operating capital. Then from capital investment they went to manufacturing cost estimate, profitability estimates, optimization studies, and various economic studies, such as variation of capital cost and profitability with capacity.

The survey work just described was coupled with experimentation. The students were expected to set up in the laboratory on a bench scale an operation of the process. In the ten weeks

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or less allotted for this experimental work it has been found that the students had all they could do to merely set up a demonstration of the process itself. This meant that their work was usually confined to reactor studies, which might have given them an opportunity to match mathematical models for the process through the use of kinetic and thermodynamic principles. This also gave them a chance to compare literature data with their actual experimental data, and gave them some conception of problems met in scale-up of processes.

For the most part the mathematical tools used were those the students had in engineering school and consisted mostly of algebra, calculus, differential equations, and error theory. However, it is hoped that in developing this sequence further, we shall be able to expand the use of various optimization and operations research techniques, such as dynamic programming, linear programming, stochastic programming, nonlinear programming, evolutionary operations, game theory, and any other concepts and techniques that may appear in the future.

An attempt was made to have the students go through economic studies a number of times at various stages in the development of the information on the process. This was to allow them to get a feel for the increasing accuracy of their cost estimates as the project progressed. This also allowed them to go through the iterative process of re-evaluating and remodifying their studies, an experience needed in design.

In addition to their written and oral weekly progress reports, which were not allowed to become too time consuming, the students had an interim report and a final report for this process development stage. The interim report was due after about four or five weeks. Format or standards of this report were not made too rigid. The quality of the final report due at the end of the first quarter, or term, was more rigidly controlled to assure that the students had developed all the essential information. Also effort was made to encourage completeness, clarity, usefulness, and workmanlike appearance.

This report contained a process study, including heat and material balances, chemical flow diagrams, and sample calculations. The economic studies mentioned previously were included. Plant location was also shown. Tied in with these studies was a write-up on the experimental findings in the laboratory with an interpretation of the data. Chemical and physical properties of the various materials processed, and needed for design purposes, were required, and salient design problems which the students were able to anticipate were discussed. Also included was a discussion of safety considerations specific to the process. This report ,then, containing the students' conclusions and recommendations, constituted the design criteria which they would use in the second phase of the program concerned with the plant design proper.

DESIGN PROJECT PHASE

In the second term the students, remaining in the same groups that were assigned in the first term, continued with more specific studies on design, where they actually took the criteria they had developed and went through the project work required. This work consisted of roughly two aspects. One aspect embraced project planning and administration. There were instructions on acquisition of equipment and services for the erection and start-up of the plant, on engineering law, erection supervision, and plant commissioning.

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The other aspect of this term was the process design. This included equipment design calculations. The tools used in these design calculations were very varied and actually drew on every course that the students had in their engineering program. They included calculations in fluid flow, heat transfer, mass transfer, reactor design, economic balances, mechanics of materials, thermodynamics, and many other disciplines. Other disciplines are being introduced as time goes on. For example, the students are showing increasing interest in process control theory. In addition to these design calculations the students were made to simulate, as much as possible, all the services which a chemical engineer and related professions would have to perform on a design project. In their final report they included an engineering work progress schedule with the help of critical path planning. The site selection made in the first phase had to be expanded from general geographical considerations to the specifics of exact location of a site. The material balance had to be worked out in more detail. A more exacting and usable chemical flow diagram was prepared, and the students were shown how to prepare a mechanical flow diagram as well. However, piping drawings, piping specifications, and pipeline designation lists, while discussed, were left optional, because it was felt that this peripheral detailing did not fit in the allotted work time. Selection of materials of construction was included. Equipment specifications had to be included on all process equipment. For vessels this meant drawings showing wall thickness, temperature and pressure requirements, location of nozzles, and other process details, but fabrication details were not required. For other pieces of ready made equipment, such as heat exchangers, pumps, and agitators, they had to fill in standard check lists of specifications with proper back-up information. More complete physical and chemical properties of materials used in the process were included.

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Operating instructions in reasonable detail were prepared for use by production supervisors. These included a process description, start-up, operation, and shut-down procedures, and maintenance instructions. Diagnostic instructions were prepared for anticipated operational difficulties. Also included were safety instructions suitable for supervising operators to prevent injury and losses due to chemical and mechanical hazards. The students were shown how to prepare an extended equipment list, which also fills a function in acquisition and cost control.

A final economic study was made showing a manufacturing cost estimate in as much detail as possible. This included a final study of return on investment as it varies with the capacity.

Our students did not become involved in more detailed civil, electrical, and mechanical engineering. Their work, for example, would be confined to specifying weight loads without design structures, specifying electrical loads without designing distributions, and specifying steam requirements without designing boiler plants. In lectures, however, they were made aware of the need and significance of these other engineering professions.

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We have made some attempt to have the students work with engineers designing in industry. Success in this direction depends greatly on geographical location. We have had limited success with architect-engineer firms in our area, and we hope to have greater success in the future.

MORPHOLOGY OF DESIGN

The full morphology and anatomy of design was followed in this program to a reasonable degree. The students' operations matched with the seven basic phases outlined by Professor Asimow[1, 2] in his *Morphology of Design.*

CHARACTERISTICS OF PROGRAM

While lectures were given during this program on principles and helpful information useful in design, the students' main exercise was the design of a specific chemical plant. We found that many of these ideas emphasized during the project are difficult to lecture in an interesting manner. Sometimes the students do not see the light until years after they have graduated, at which time they come back and thank the teacher. Lectures on theory and practice of design should be timed, if possible, so that the subjects discussed come up at the same time they occur in the project work.

As regards computers, it is not recommended that it be made into strictly a computer course. The policy has been to encourage the students to use computers when a computerized problem is indicated. This might occur where there are long, detailed iterations required, or where some logical decision network is needed. Computers should not become the be-all and end-all of the program, but rather they should be presented as a valuable tool of serious philosophical portent.

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