

THE CHEMICAL ENGINEERING PROCESS DESIGN SEQUENCE AT VIRGINIA TECH..... AND A NEW PERSPECTIVE*

J. PETER CLARK

*Epstein Process Engineering
Chicago, IL 60609*

WHEN I LEFT Virginia Polytechnic Institute and State University (Virginia Tech or VPI&SU) in 1978 to take a position in industry, I wrote the following description of the Process Design Sequence at VPI&SU to record what had been done and to provide some assistance to my successors. To that description, I have added a postscript that reflects my new perspective.

INTRODUCTION AND OVERVIEW

THE PLANT DESIGN AND economics sequence of courses has been, with the unit operations laboratory, an important and distinctive part of the curriculum at VPI&SU. The nine hours offered are somewhat more than are offered in most departments. The style of the sequence has evolved over the years and has reflected both the instructor and the educational conditions prevailing at the time.

The founder of the department, Dr. Vilbrandt, wrote several editions of an important early text on process design [1]. In a paper he wrote describing the course as he taught it, he emphasized the laboratory orientation of the design experience. Students began in the Fall with one or more major projects and worked as teams for the rest of the year. Some examples, found in departmental files, are recovery of zein from corn and

**In addition to being one of the
few professional activities that is explicitly
taught in school, design is the one course in which
students learn to think in a new way, and
to synthesize what they have learned . . .**

*Paper presented at ASEE Annual Conference 1979, in Baton Rouge, LA.

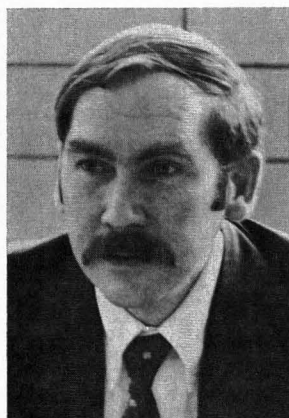
production of penicillin. The course met for one hour of lecture and six hours of lab each week all year. The student teams gathered critical data needed for a design by performing experiments in the laboratory. At the same time, the students were each completing a senior thesis.

At some point, a course on industrial economics offered by the industrial engineering and operations research (IEOR) department was included in the curriculum and so, presumably, the lectures on design emphasized such matters as equipment sizing and layout. One component of the final reports was a scale model of the proposed plant.

By 1972, the course had evolved into a less integrated sequence but with the same sort of schedule. The Fall quarter had some economics, but the students still took Industrial Engineering Economics. The senior thesis had disappeared, but some students did undergraduate research. It was common to introduce a major design case study late in the Fall and then have groups work most of the Winter on the same case. Several of the cases published by Washington University were used this way, especially one (on cellulose triacetate) that had been developed at VPI&SU in cooperation with Du Pont. Spring quarter was a kind of wrap-up course that was intended to help prepare the seniors for their careers and was not designed to be very demanding, in recognition of Spring fever and senioritis.

When I assumed responsibility for the sequence in 1972, I followed much the same pattern: Fall was a sort of pre-design experience, emphasizing process synthesis; Winter relied on a major case, usually some portion of the cellulose acetate study; and Spring was more specialized, emphasizing simulation, optimization and computers.

About 1975, the curriculum was revised to drop the IEOR economics course on the grounds that chemical engineers needed a different empha-



J. PETER CLARK received his B.S. in Chemical Engineering from Notre Dame and his Ph.D. from the University of California, Berkeley. He was Assistant and Associate Professor at Virginia Polytechnic Institute and State University from 1972 to 1978. Before that, he spent four years with the U.S. Agricultural Research Service. He is a registered professional engineer in Virginia and a member of AIChE, ACS, ASEE and IFT. He was Director of Research at ITT Continental Baking before becoming President of Epstein Process Engineering.

sis. At the same time, credit for senior seminar was removed and the Monday lecture hour was dedicated to visiting seminar speakers. Don Michelsen, who had a special interest in economics, took over the Fall course and experimented with personalized system of instruction (PSI) using several economics texts. He also tried the idea of using teams of students as consultants to industry. PSI was a mixed success; the team studies were better received. As part of the reorganization, the Winter and Spring courses were combined for six hours in the Winter. This meant that there were no required courses in the Spring, and so the number of early graduations increased.

I divided the new Winter combination into a "group" course and an individual course and treated the six available credits as one course with + or - grades possible. For half the grade, each student did a major project of his choosing; for the other half, he worked on several smaller studies which were assigned by me and often done in groups. In 1978, due to the larger number of students, all students did the AIChE Student Contest Problem as the individual project. Also, in 1977, I inherited the Fall course on economics because Don left the teaching faculty temporarily. The hours were changed to three hours of meeting plus the seminar, and the course became a more conventional lecture course.

Thus, the history of the sequence has been evolutionary. It has yet to be nominated as any-

one's favorite, but the complaints about overwork seem to have been satisfied by the combination of the Winter and Spring courses. In 1978, there were at least nine outstanding (in my opinion) entries for the student contest problem; it was hard to select the two that could be submitted. Student teaching evaluations have consistently improved over the years, which may be a reflection of experience, but are yet to reach the highest level. That may reflect the fact that it is a required and difficult course. In general, I feel the course sequence is good for its purpose, but I do not mean to suggest that another way might not be better.

PROCESS ECONOMICS

SO FAR, three texts have been used: Jelen [2], Woods [3], and Peters and Timmerhaus [4]. I planned to use a fourth, Happel and Jordan [5]. In 1977, I chose to lecture to one large section for one hour on Monday and two on Wednesday, rather than repeat the lectures to two smaller groups which would have then met every day.

There were two major objectives: 1) convey the essentials of process economics, especially the

It has been suggested to me, by a professor elsewhere, that doing the contest problem be seen as a privilege urged only on the best prospects while the others do something else, perhaps in groups of two or three.

measures of worth such as discount cash flow and present worth, along with some information on taxes, depreciation and accounting; and 2) discuss the nature of the chemical industry and chemical engineering careers.

For the second part, I drew upon ideas from the recent book by Wei and Russell [6]. The students each prepared term papers on one chemical company of their choosing and on one chemical of their choosing. They also did homework problems from Peters and Timmerhaus, but I took the chapters out of order, which, in retrospect, did not work well. I recommend using any text in the order written, as a general rule. I gave one in-class exam and a final. We spent a fair amount of time discussing career opportunities, including graduate school, interview techniques and so forth. The Fall is the time to do this, as recruiting is heaviest then. I demonstrated, using present worth, that the discounted value of cumulative before-tax earnings for a chemical engineer with a Ph.D. was greater (in less than ten years) than that of

one with an M.S. and that his was greater than that of one with a B.S. This elegant proof did not seem to affect any decisions, sad to say.

PROCESS DESIGN

MY PATTERN in the six hour Winter quarter pair of courses became fairly stable. About half of the credit was earned by an individual project and the other half was earned from a collection of assigned group and individual projects. There were no exams or final. I used both individually selected projects and the AIChE student contest problem. My practice was, since 1974, to solve the student contest problem myself over Christmas vacation. For three years, this was merely an enjoyable exercise of my skills; in 1977, it was valuable preparation for the course. Only about the top quarter of the class is really capable of doing a good job on the problem, in the sense of preparing a competitive solution. It has been suggested to me, by a professor elsewhere, that doing the contest problem be seen as a privilege urged only on the best prospects while the others do something else, perhaps in groups of two or three.

Part of me accepts this, while another part is concerned that we might miss some good work from latent stars or that, given the choice, no one will really exert themselves. I have not resolved this problem. I feel that our students have a decent chance in any year at any one of the cash prizes and so would like to have as many as possible make the effort.

The contest problem is always a challenge and I believe few students will attempt it voluntarily or for no credit. Thus, I favor some compulsion to get entries. I also feel that at least once before they graduate, they must stand on their own and do one comprehensive design exercise. The difficulty is that counseling and then grading over fifty such exercises is rather time consuming for one person.

By comparison with other engineering departments, chemical engineering at VPI&SU demanded more of the students, but we also gave more credit. In addition to the individual project, I have had good success with exercises involving outside help. There have been two categories: 1) a novel compound described by a chemist [7], and 2) a project involving someone from industry.

Hamp Smith, from Chemistry, worked with me for three years (more or less in exchange for a lecture by me to his class). He and/or another

professor (Jim Wolfe in 1978) came to the class and described some compound they had synthesized. They alone had all the information available on this compound. We created some reason for being interested in the substance, (Wolfe had a potential anti-epileptic drug). Groups of students were assigned the problem of designing and estimating the cost of a plant to make some large quantity of the compound, say several million pounds. The chemists were very cooperative and the students seem to like the exercise. Ideally, it should come late in the course, after some other practice, but not so late that it conflicts with the individual project, which they inevitably put off until late.

The other class of project was mainly an excuse to get an industrialist into the class. In past years I had help from Lannie Robbins of Dow (recovery of acetic acid), Al Conner of UOP (catalytic cracking), Keith Baugher of Exxon (cat cracking), and Bob Bickling of Du Pont (cellulose acetate). I usually presented an agreed-upon case to the class and let them struggle for a while. Then the visitor came to serve as a consultant and critic. I graded the reports. The students liked these exercises. The key here is planning for the best use of such help. Unfortunately, it does not relieve the grading load, which is the major time demand.

Another class of exercise which has been successful, usually at the first of the quarter, involves the past student contest, whose solution is published in the Fall Student Members Bulletin from AIChE. I usually ordered about 70-100 of these as student chapter counselor. In my experience, there is always something that can be improved upon in the winning solution. I assigned the problem of finding an alternative solution, correcting (or at least checking) the solution or some other excuse for reading the winning report very carefully. This, I hoped, would create some sympathy for my difficulties in reading their own reports and it may have convinced them that it was not that hard to excel in the contest.

Whatever the first assignment may have been, I announced after it was turned in that it would not affect their grade, but I criticized it as if it would. This gave them a feel for my standards and it gave me a measure for whatever improvement may result from the course. In past years, I felt that the improvement was significant, which was gratifying.

Other exercises I have used over the years have

come from various sources, such as the cases published by AIChE under Jud King, Sherwood's book [8], my own experiences, and articles in CEP. I tried to have about five or six graded exercises.

For a text, I have used both Peters and Timmerhaus and Baasel [9]. Jim Douglas has a new book in manuscript which I reviewed in part for a publisher. It looks promising, but has not yet appeared. Peters and Timmerhaus is being revised but will not be out in a new edition until 1980; right now, I feel it is out of date and that the combination of Happel and Jordan with Baasel is better.

I found an entertaining way of forming groups. I selected the appropriate number of people, say 15 if I wanted 4 person groups in a class of 60. The first time I selected people whose combination I felt would provide an unfair advantage, i.e. some of the better students; but I usually included some "sleepers"—people I felt needed some leadership experience. We retired to another room and held a draft, using the roll sheet. The last to pick on the first round got the first pick on the second round to make things more equitable. I determined the order of picks more or less arbitrarily. It was most informative to learn who in the class got picked in what order. On the next group project, I either kept the same leaders but allowed them to "protect" only one of their group, the rest becoming available to the draft, or I chose new leaders. There is usually a chance to do both during the year. The student evaluations of their peers were most useful to me and usually conformed with my own assessment once the grades were computed. Sometimes the students learned some valuable lessons also; one year, the last man picked on the first round was protected on the second round.

The substantive material of the Winter course is well described in my little series of articles in *Chemtech* [10]. Most of class time was spent discussing the current case, but somewhere during the course, I tried to cover the essentials of design as I saw them. There was a very heavy emphasis upon good writing, neat flow sheets, accurate material balances, clear and correct economic estimates, and good judgment. I found that estimation of physical properties was always a need, as was proper citation of references in reports.

As the title of my article suggests, I emphasized preliminary design, as do Baasel and Douglas, which is why I like their books. This

means teaching a kind of creative sloppiness, which is foreign to the student after the relative rigor of his junior year courses. There is a proper place for rigor, of course, as there is for computer-aided design, which is also an interest of mine but which I did not emphasize in the course. I tried to have the students do at least a few tedious calculations of non-linear material balances or adiabatic flashes so they would appreciate what the computer could do for them. However, it wasn't convenient or practical to have the class use FLOWTRAN or CHESS in the past. Another instructor might find a way; certainly, many in other schools do [11].

I did have a good experience with a small business game taken from *Chemical Engineering Education* [12]. One student developed the code for the Department's PDP-11/40 and the other students competed in groups.

The resources available to assist an instructor of process design are limited only by his imagination [13]. There are over 20 cases from Washington University, 14 from the King project with AIChE, and about 46 past student contest problems from AIChE. Only a handful of these resources are needed to get through the year. I have developed some others of my own, but so can anyone who wishes to do so.

POSTSCRIPT

AS AN EMPLOYER of chemical engineers in industrial research and development, I now see the process design sequence differently than when I taught it.

We do very little process design in the sense that most courses discuss the topic or in the sense that design firms or groups actually practice the trade. Probably, that is true for many chemical engineers employed in operations, research or technical service. Is design then irrelevant to us? Far from it!

In addition to being one of the few professional activities that is explicitly taught in school, design is the one course in which students learn to think in a new way, and to synthesize what they have learned elsewhere. These are critical skills in any career, as many people agree. I also feel that a good design experience helps convert students into engineers by convincing them that they actually can perform competently and relatively independently in the face of pressures and the challenge of more ill-defined problems

Continued on page 42.

experiment or process system. Good illustrations.

Chapter VII: For the mechanical type laboratory oriented research person, this is a most practical chapter. Excellent descriptions and illustrations; most useful to anyone engaged in vacuum processing and systems design.

Chapter VIII: Good treatment of very complex subject matter. Simultaneous mass and heat transfer is not the easiest subject to learn or to adapt the theory to practical usage. This is the most difficult material for the non-engineer to understand unless the user has an excellent background in mathematics and good mechanical aptitude. Would suggest that whenever possible, more diagrams and sketches be added to simplify the material. Extensive calculus used.

Since all chapters are written by different authors, it is suggested that in the next edition a section be added that lists all of the nomenclature for all chapters.

In comparing the stated role of the book against the included techniques in the included chapters, it is found that in some instances there is little laboratory technique discussed. Also, the level of mathematical derivations is not consistent in the several chapters. □

PROCESS DESIGN SEQUENCE

Continued from page 37.

than they have seen before.

It is almost commonplace now to emphasize the importance of communications in professional advancement, and, at the risk of being trite, I must add my endorsement. Design courses usually require good report writing which students usually detest as an apparent over-emphasis on what they see as style as compared with substance. If anything is true, there must be more emphasis put on good writing and speaking. Facility in these areas is far more useful in practice than glibness with the computer.

Finally, one of the first skills a chemical engineer learns is how to do material and energy balances. These are also among the first steps in most design exercises. I feel strongly that these steps should be among the first in nearly any engineering assignment associated with processes. It may sound obvious, but it is too often forgotten how useful a simple balance can be in operations and research. Many of the steps taught in design sequences really do have other applications, and students should learn that fact.

In general, the chemical engineering taught in universities is more sophisticated than that practiced in many industries. Certainly, this is true for the food industry! Are students over-educated, as one might be tempted to say? I do not believe so.

Chemical engineering, culminating in the design sequence, is a grand education in analytical skills, modern science and technology. It is interesting enough to attract intelligent students and challenging enough to stimulate even the best. Furthermore, the influx of new concepts brought by products of this fine education will gradually change the industries they join. Far better that education continue to stress the new and sophisticated than the old and familiar—how else will we ever grow?

Having now been on both sides of the process design course "debate" (if there is such a thing!), I feel strongly that a varied, challenging and comprehensive course is essential to a complete chemical engineering education. I tried to provide such an experience when I taught and I look for the results in those I hire today. □

REFERENCES

1. Vilbrandt, F. C., Dryden, C. E., *Chemical Engineering Plant Design*, McGraw-Hill, N.Y. 1959.
2. Jelen, F. C., *Cost and Optimization Engineering*, McGraw-Hill, New York, 1970.
3. Woods, Donald, *Financial Decision Making in the Process Industry*, Prentice-Hall, 1975.
4. Peters, M. S., Timmerhaus, K. D., *Plant Design and Economics for Chemical Engineers*, 2nd ed., McGraw-Hill, New York, 1968.
5. Happel, J., Jordan, D. G., *Chemical Process Economics*, 2nd ed., Marcel Dekker, New York, 1975.
6. Wei, J., Russell, T. W. F., Swartzlander, M. W., *The Structure of the Chemical Processing Industries*, McGraw-Hill, N.Y. 1979.
7. Clark, J. P., *Chemistry as a Foreign Language*, *Chem Tech* 7 (12), 747, (1977).
8. Sherwood, T. K. *A Course in Process Design*, M.I.T. Press, Cambridge, Mass. 1963.
9. Baasel, W. D., *Preliminary Chemical Engineering Plant Design*, Elsevier, New York, 1976.
10. Clark, J. P., *How to design Chemical Plants on the Back of an Envelope*, Parts, I, II and III, *Chemical Technology*, 664 (1975), 23 (1976) and 235 (1976).
11. Clark, J. P., Sommerfeld, J. T., *FLOWTRAN Usage Education*, *Chemical Engineering Education* X, (2) 90 (1976).
12. Russell, T. W. F., Frankel, D. S., *Teaching the Basic Elements of Process Design with a Business Game*, *Chemical Engineering Education*, XII (1), 18 (1978).
13. Clark, J. P., Letter to editor (re case studies), *Chem-Tech* 6 (3), 146 (1976).