Engineering Journal of Qatar University, Vol. 3, 1990.

"CHEMICAL ENGINEERING DESIGN"

PLANT PROJECT PROCESS PHRESHMAN

By

Dr. Robert N. Maddox
Emeritus Leonard F. Sheerar Professor

The 23rd Annual Phillips Lecture in
Chemical Engineering Education
April 11, 1989

Sponsored by
Phillips Petroleum Company

and

School of Chemical Engineering
Oklahoma State University

1. INTRODUCTION

When Dr. Robinson first approached me with the news that the faculty of the School of Chemical Engineering had selected me as their 1989 Phillips Lecturer I was, quite frankly, overwhelmed. The unexpected and unanticipated always seems to give the greatest pleasure.

The Phillips Lecture was initiated to be unique among distinguished lectureships in American Universities. It was in 1967, and so far as I know still is, the only lecture series devoted to the subject of Chemical Engineering Education. Prior to today some of the most distinguished names in Chemical Engineering have graced the invitation to attend the Phillips Lecture and listen to an elaboration on some aspect of education that is of particular importance and significance. The faculty here exert great efforts to make the Phillips Lecture a memorable experience for the speaker. Over the years they have been rewarded by the presentation of outstanding discourses on various aspects of Chemical Engineering education.

Before beginning the formal presentation let me give you a little of my background, some of which many of you will not know. I graduated from high school in Winslow, Arkansas, a small town of about 300 people, in May of 1941. I was the valedictorian of a five man (literally) graduating class, which meant simply that I was the only one whose parents took any interest in the education of their son and expected good classroom performance. Money was short, so I stayed out of school a year and worked splitting white oak fence posts, before enrolling as a phreshman at the University of Arkansas in September 1942. I had always dreamed of being a chemist but an older graduate of Windslow who graduated in 1942 from the University of Arkansas gave me the only job counseling and career counseling that I received - when he found out I was interested in chemistry his remark was "Take Chemical Engineering it is better than chemistry." Consequently I enrolled in Chemical Engineering. I volunteered for the Naval Air Corps in the spring of 1944.

Discharged after World War II, I re-enrolled as a chemical engineering student at the University of Arkansas in 1946 and graduated in may 1948. Because of one of my serior year instructors, who had just completed his masters at the University of Oklahoma, I enrolled there for graduate school. Subsequently I came to Oklahoma State University and, against all urging and counseling by my major professor, decided to join the faculty here - a decision I have never regretted. I had wanted to be a teacher for as long as I can remember. When I learned about "professors" the transfer was immediate. Please note this was at least thirty years before publication and my reading of "This Beats Working for a Living" (1).

I have enjoyed immensely being a professor, and feel that I have been a reasonably good teacher. If I could change anything about my professional life, it would probably by my decision to retire. After I made that decision, the State of Oklahoma, Oklahoma State Unversity, and some people reversed their position on some of the ground rules. That I am not allowed to reverse my decision seems just a bit unfair.

During my graduate study at the University of Oklahoma I took the first meaningful design course to which I had been exposed. The "design" that I studied at the University of Arkansas was actually a course in stoichiometry because the new department head, who came in at the beginning of my senior year, was appalled to find that the senior class had never studied stoichiometry. Consequently I took "design" from Lewis and Radasch (2). The graduate design course at OU was the primary reason I was employed in the position of process engineer for Black, Sivalls and Bryson, Inc. in Oklahoma City. In that position I was privileged to be involved in the developing natural gas industry. I participated in the development of glycol dehydration, glycol injection and field stabilization of hydrocarbon liquids, and sweetening processes for H_2S and CO_2 removal. I was responsible for the design, construction oversight, and start up of (so far as I know) the first glycol injection/mechanical refrigeration plant built for increased liquids recovery from natural gas streams. The emotions that surface when the first product flows from a plant you have designed and built I can only describe by comparison to the emotions one feels when he first holds his first born child in his arms. The love affair that developed between Maddox and design after that first experience is the reason for the title and subject matter of today's Phillips Lecture.

In searching for topics to present today there were two that were almost equal on my list of priorities. On the world business scene today ethics is much in the forefront. We hear and read daily of the need for guidelines on ethics in public office, in appointive positions, and, yes, even in education and higher education. That would be a most interesting and challenging subject. There seems to be a wide spread and almost universally held view point today that whatever is legal is proper. That there need to be at least guidelines if not laws on what constitute proper and improper actions. My view of this sort of thing is quite simple. If a person in a position of responsibility and paid by the tax payers of Oklahoma needs a rule or law to tell him/her that he/she should not take time on his/her job and use his/her secretary, state letter head, envelopes and postage, to invite people to a partisan political meeting then that individual has no business at all serving in the position that he/she has. This viewpoint, of course, leads me to the conclusion that ethics is not a subject matter that can be taught in a one three hour course or, for that matter in thirty-three hour courses. I say this in spite of the fact that several colleges and universities are establishing centers and curricula to teach ethics in business. No course can anticipate all of the possible complexities of modern day life that make an ethical solution to a situation difficult to define. The doing of what is right has to be something that one has grown up with and tried to practice as he/she growns and matures into adult hood.

Design on the other hand is a subject that can be taught. At least every chemical engineering department is cetainly making an effort to teach design because the Accreditation Board for Engineering and Technology (ABET) says that some magical percentage of the engineering designated credit hours in the curriculum must be "design". And what do they mean by design? This is where things begin to get just a little bit difficult. People involved in accreditation have been struggling with trying to define engineering design ever since I have been in the teaching profession. The current ABET definition of design is (3):

I. Engineering Design

(a) **Engineering Design is the process of devising a system, component, or process to meet desired needs. It is a decision - making process (often iterative), in which the basic sciences, mathematics, and engineering sciences are applied to convert resources optimally to meet a stated objective. Among the fundamental elements of the design process are the establishment of objectives and criteria, synthesis, analysis, construction, testing and evaluation. The engineering design component of a curriculum must include at least some of the following features: development of student creativity, use of open-ended problems, development and use of design methodology, formulation of design problem statements and specifications, consideration of all alternative solutions, feasibility considerations, and detailed system descriptions. Further, it is essential to include a variety of realistic constraints such as economic factors, safety, reliability, aesthetics, ethics and social impact.**

(b) Courses that contain engineering design normally are taught at the upper division level of the engineering program. Some portion of this requirement must be satisfied by at least one course which is primarily design, preferably at the senior level, and draws upon previous course work in the relevant discipline.

Changes are being considered in the statement of criteria concerning engineering design but the basic design statement in the proposed changes is, so far as I can discern, the same.

I think that one of the great difficulties ABET faces in trying to establish a satisfactory definition for engineering design is the attempt to be comprehensive. I must confess that when I was department head I was concerned only with design in chemical engineering. I did not appreciate the differences that exist between what constitutes design across the various engineering disciplines.

Several years ago when I was still Department Head a new dean for the College of Engineering was appointed. He came from a different engineering background than chemical engineering and I felt called upon to try to explain to him what we chemical engineers meant by design. After considerable thought I selected two examples from projects that I had the opportunity to be involved in. The first of these dealt with the design of a central fractionation facility for separating a feed stream into various light hydrocarbon liquid streams. This seems like a simple enough assignment until you consider that the feed streamn was going to be effluent from a pipeline which had not yet been built and for which contracts for purchase of liquids from the various processors along the line had not been consummated. Design of the plant had to proceed, however, because it needed to be ready for product when the pipe line started flowing. At that time shop space for fabrication of vessels was so tight that a lead time of almost two years was necessary. For this reason we had to reserve space for certain of the major vessels and, so, the design exercise started. The ultimate capacity of the plant was relatively easy to settle on but the possible feed streams covered a wide range of compositions. When I outlined this problem to the dean his comment was, "That is impossible." I pointed out to him it was not impossible because we had done it and that the plant worked satisfactorily. I am not certain that he believed me then nor believes me now.

The second instance concerned a company with which I had been involved as a consultant for a number of years. During the time of my ivolvement the company production of natural gas liquids had increased by more than an order of magnitude. In that same time frame the number of people employed in operations for the company had decreased by at least an order of magnitude. During all of this automation that had gone on I had not solved a single differential equation. The new dean's comment was "They should hire technicians". End my attempts to enlighten him about chemical engineering design problems.

My exposure to attempting to develop a meaningful curriculum for a university in one of the developing countries has led me to a much greater appreciation of the differences that exist in what constitutes design for an electrical engineer, a mechanical engineer, a civil engineer, and a chemical engineer. The ABET definition must cover these four disciplines, and others.

Another thing that causes difficulty is that ABET is attempting to develop a definition for something taught in the classroom which, after graduation, takes place in a industrial environment. The crossbreeding of these two is extremely difficult if not impossible.

I still remember our first group of Professional Program (4) interns who spent their summer practice working with companies in the petroleum and petrochemical industry doing "real live" designs. Upon their return to school they were horrified to learn (at least some of them were) that the companies were actually contemplating spending real honest to goodness money to build the things that they had designed during the summer. Normally this is an expectation which we cannot achieve in the classroom. There is no way to convince a student in design at Oklahoma State University that the School of Chemical Engineering is going to spend X-millions of dollars building the plant that he has designed.

There is yet third difficulty. I will illustrate this example. I recently read (5) a definition of research. The author said:

> (a) "Research is the careful, systematic, patient study of some field or aspect of a field that the researcher hopes will reveal facts, principles, or some segment of the illusive truth".

That seems to me to be a reasonably good statement of what research is. However, if you submit that definition to a committee, particularly a committee composed of learned academicians from several different scientific and engineering fields, it will grow, expand, and multiply until the final product could hardly be recognized as having sprung from the simple definition above.

Let me give you an example of what I mean. In the ABET statement of engineering design the word "optimally" is used. In terms of a chemical engineering plant how would you define the word optimum? I can think of several possible meanings for the word:

(a) The plant that would be most profitable.
(b) The plant that would produce the specified product at lowest cost.
(c) The plant that would make the maximum amount of the specified product.
(d) The plant that would be easiest to operate. This could have great merit in a geographical area where operators are unskilled.
(e) The plant that would require the least maintenance. Again, this could be a strong consideration in areas where maintenance support is lacking.

There are undoubtedly other difinitions but I am sure you begin to get the idea that "optimal" is not a single definition word when applied to the design of a chemical plant.

One more nitpicking comment about the ABET definition of design. In the definition the statement is made "... consideration of all alternative solutions, ...". According to one authoritative estimate (6) a given chemical engineering process can have as many as 10^4 to 10^9 alternative possibilities for stream flows. There is no reasonable way in which "all" of those possible alternatives can be investigated conclusively within the limited time frame that is allowed either for a class problem or a real case of design of a chemical process or plant.

Suffice to say that most engineering educators accept the fact that design must some how or other be taught in their discipline. Because the powers that be (ABET) specify an inordinate number of hours of design, we find ourselves in the ridiculous situation of breaking courses into so much, or a certain percentage, of engeneering science and so much more of the remainder being design. Personally, I find this practice abhorrent but none the less I followed it when I was department head in order to meet the "minimum criteria" required for an accreditable curriculum. I think there is place in the chemical engineering curriculum for about four cources aimed at design with the remainder being engineering science. Hopefully the time will come when the accreditation criteria are sufficiently flexible to alow this kind of approach.

One important thing to keep in mind throughout this discussion of design is that the education of the chemical engineer must fill two needs:

(a) Provide a background that will enable the engineer to be productive through a forty year career.
(b) Give enough specific information and skills to make the engineer job efficient whithin a resonable time after reporting to work.

Another thing that must be kept in mind is that the design course, or courses, is not going to turn out one who is an accomplished process or plant designer. One course in thermodynamics does not make a person thoroughly knowledgeable about thermo; satisfactorily completing a three credit course in transport phenomena does not equip one to be a world-class research worker in the field. Completion of the introductory course(s) in design does not give one the skill necessary to design a billion dollar istallation without help or supervision. The introductory course in design does give the student an opportunity to see the interrelationship of courses from various subject matter areas; a view of how cost influences engineering decisions; experience at writing reports dealing with paper work rather than experimental measurements; a view of how other engineering disciplines integrate things with Chemical Engineering. In spite of what some may thick (7), these things are important to those graduates who go into sales, technical service, operations, and yes, even those who go into process design.

Let's narrow our view a little now and look at design in chemical engineering. My observation over the years is that there have been four different ways in which design is taught to chemical engineering students.

These are:

(a) Plant Design
(b) Project Design
(c) Process Design
(d) Phreshman Design

There have certainly been some variations in these four categories but I think they serve as a reasonable frame work for our discussion here. The ABET criteria do not at the present time specifically allow for accomodation of a phreshman "design" course. However, many institutions across the country offer such cources. They are intended to be "fun" courses which, while allowing students to demonstrate their creativity and ingenuity, give the person in charge of the course the opportunity to point out to the students their need for more advanced engineering knowledge to conduct a truly meaningful design. Certainly this type of course could have great value in "selling" engineering to promising students. The course could also help students understand the necessity for certain subject matter occupying a significant portion of their study time. One of the great drawbacks to such a course is that, for it to be a truly worthwhile course, the instructor must be one of the most competent faculty. This means one of the most valuable faculty is going to be asked to devote a major portion of his time to teaching phreshmen what amounts to, in many instances, gadgeteering. In an ideal world such a thing might be practical. In the practical world such ideals are seldom achieved. A phreshman design course taught by a teaching assistant or junior faculty member almost by definition is not worth the credit hours and time devoted to it. In addition to this, my personal limitations are such that I have been unable over the years to come up with meaningful chemical engineering design problems that are within the realm of possibility for phreshman students to solve. I admit this as a personal limitation on my own creativity and ingenuity. However, visits to institutions where this kind of course has been tried have not given me much insight into how to make such an experience worthwhile. I remember clearly one case were students had "designed" an offshore platform for oil and gas production. When I attempted to question the students about materials selection, corrosion, loading-to-support weight ratios, and such other practical matters their responses showed that never, in the full semester of that course, had they ever considered such things. What they had done was take some balsa wood and some glue and spent a lot of time gluing together what did bear some superficial resemblance to an offshore production platform. What they had not done, so far as I could ascertain, was any chemical engineering design on their platform. As a matter of fact, my experience says that the supporting structure of the platform is normally not designed by chemical engineers. Rather we get involved in the separation and processing equipment that sits on the platform.

For this reasons I suggest that phreshman design not be considred further. Instead I suggest that faculty make a serious and sincere effort to incorporate in their teaching of introductory courses in chemical engineering problems that bring to the fore the need for more information in order to achieve a complete solution. Very few such problems exist in the current problem sets provided in the text books. Developing such problems is a challenge but the rewards will be great - more interested and better motivated students in the upper level courses in chemical engineering.

In plant design, as I use the term, the students in a design class undertake the design of a complete chemical plant. Typically the students will be divided into three or four man "teams" with each team member assigned short term individual tasks that require from a few days to a few weeks to complete. This approach should get the students invloved in such things as the geographical location of the plant, source or raw materials, consumer markets, sources of power, effect of climate, transportation facilities, lay out of the plant not only from a process but safety and environmental standpoints, and drainage and waste disposal.

The engineer doing a complete plant design also has to become involved in choices such as whether to use a positive displacement or cetrifugal pump. Of what material should the impeller of a centrifugal pump be made? What size should the line from the distillation column top tray to the overhead condenser be? Should valve, perforated, or buble cap trays be used or should the column be packed? If it is a packed column should it contain random packing, stacked, or what is now reffered to as structured packing? In other words, the complete plant design requires attention to all of the myriad small details many of which will depend on decisions not even made by the engineer representing the company building the plant. Vendors have knowledge and expertise that they make available in order to try to sell their products.

Industry has, in recent years, taken a great interest in the teaching of plant design. In cooperation with the American Institute of Chemical Engineers they have provided a number of "case studies" of plant and process unit design which can be used in the classroom. In many instances companies have agreed to have one of their senior design engineers work with the faculty member in a nearby institution in presenting such case studies for student work. Some of my good friends have used this approach and say that they are exceedingly pleased with the results. In my own case, I would have difficulty in teaching a design course centered around the work of someone else, in which I could only guess why certain decisions were made and things were done in certain ways. In addition to this I think that many details that are required for a complete plant design are, in general, beyond the capacity of a single individual to bring to the classroom.

As an indication of the type of details I have in mind, consider these three examples:

(a) You are doing a complete design for an amine sweetening unit using DGA. For the reboiler tubes, where corrosion is severe, which of the stainless steels in Figure 1 (8) would you recommend for use?

(b) You need to Heat Trace a part of a plant. Required input for the computer program (9) is shown in Figure 2.

How comfortable would you be making the specifications for required input?

(c) The plant you are designing is to use Welding Outlet Fittings. According to a recent article (10) your responsibilities include the items shown in Figure 3.

You also should "consider" the supplementary requirements shown in Figure 4.

To qualify W.O.F. manufacturers, you should visit their plant and check on the items shown in Figure 5, among others.

corrosion resistant grades

	designations*				typical chemical composition						mechanical properties at 20 °C (68 °F) annealed condition			characteristics and uses
	VALINOX	AFNOR	DIN/WN	AISI - UNS	C max.	Cr	Ni	Mo	Cu	others	U.T.S. MPa min.	Y.S. MPa min.	E % min. 5 d	
austenitic grades	VLX 304 N	Z 2 CN 18-10 Az	1.4311	304 LN	0,03	18	10			N 0,15	550	240	40	similar to 304 L with improved mechanical properties
	VLX 304 S	Z 1 CNS 18-15	1.4361		0,015	17,5	15			Si 4 %	540	220	40	specifically for nitric acid under highly oxidizing conditions
	VLX 316 N	Z 2 CND 17-12 Az	1.4429	316 LN	0,03	17	13	2.25		N 0.20	600	280	40	similar to 316 L with increased strength
	VLX 316 U	Z 2 CND 18-14	1.4429/1.4435	316 L	0,03	17,5	14,5	2.6		N 0,12	490	210	45	special grade for urea synthesis applications
	VLX 252	Z 1 CND 25-22 Az	1.4466		0,02	25	22	2		N 0,12	540	260	30	specific grade for use in urea strippers
	VLX 310 L	Z 1 CNNb 25-20	(1.4547)	310 L	0,015	24,5	20.5			Nb 0,20	490	215	40	special for nitric acid
ferritic austenitic grades	VLX 534	Z 2 CN 23-04 Az	1.4362	S 32304	0,03	23	4			N 0,15	600	400	25	improved corrosion properties over 304 L, good resistance to SCC
	VLX 547	Z 2 CND 25-07 Az	(1.4460)	S 31200	0,03	24,5	7	3		N 0.20	700	450	25	good resistance to SCC and chloride ions
	VLX 562	Z 2 CND 22-05 Az	1.4462	S 31803	0,03	22	5,5	3		N 0,17	680	450	25	good resistance to SCC and pitting
	VLX 569	Z 2 CND 18-05	1.4417	S 31500	0,03	18,5	4,7	2.7		Si 1,7	630	440	30	good results against SCC
super austenitic grades	VLX 904	Z 1 NCDU 25-20	1.4539	N 08904	0,02	20.5	25.5	4.5	1,5		550	230	40	chloride resistant grade, sulphuric and phosphoric acids
	VLX 920	Z 6 NCDU 35-20	(2.4660)	N 08020	0,07	20	35	2.5	3,5	Nb + Ta	550	240	30	same as VLX 904 with better resistance to SCC
	VLX 928	Z 1 NCDU 31-27-3 Az	1.4563	N 08028	0,02	27	31	3.5	1		500	210	35	chloride and SCC resistant grade, sulphuric and phosphoric acids
	VLX 954	Z 1 CNDU 20-18-6 Az		S 31254	0,02	20	18	6	0,8	N 0.20	650	300	35	resistance to chloride ions, sea-water environment applications
nickel alloys	VLX 800 VLX 800 H	Z 8 NC 32-21	1.4876	N 08800 N 08810	0,1	21	32			Al Ti 0,4	450	170	30	high temperatures with a very good resistance to SCC
	VLX 825	Z 3 NCDU 42-22	2.4858	N 08825	0,05	22	42	3	2	Ti 0,8 Al 0,1	585	240	30	almost immune to SCC in chloride environments, phosphoric acid
	VLX 600	Z 8 NC 75-15	2.4816	N 06600	0,1	16	76			Fe 8	550	240	30	very high temperatures, high resistance to SCC in wet environments
	VLX 625	Z 8 NCD 60-20	2.4856	N 06625	0,1	21	60	9		Ti Al 0,4 Nb + Ta 4	830	415	30	excellent corrosion resistance to most media, also resists carburization and nitriding
	VLX 685	Z 1 NCDU 43-22	2.4419	N 06785	0,015	22	≥ 43	7	2		620	240	40	special grade for handling sulphuric, phosphoric and superphosphoric acids

* Designations between parentheses are approximate

Figure 1a : Grades of Stainless Steels Available from One Supplier.

standard stainless steel grades

	designations*				typical chemical composition					mechanical properties at 20 °C (68 °F) annealed condition		
	VALINOX	AFNOR	DIN/WN	AISI/UNS	C max.	Cr	Ni	Mo	Others	U.T.S. MPa min.	Y.S. MPa min.	E % min. 5 d
ferritic and martensitic grades	VLX 410	Z 12 C 13	1.4006	410/S41000	0,12	13,0	—	—	—	420	210	17
	VLX 420	Z 20 C 13	1.4021	420/S42000	0,20	13,0	—	—	—	650	450	17
	VLX 430	Z 10 C 17	1.4016	430/S43000	0,12	17,0	—	—	—	420	250	17
austenitic grades	VLX 304	Z 6 CN 18.09	1.4301	304/S30400	0,08	18,5	9,5	—	—	490	200	45
	VLX 304 H	Z 8 CN 18.09		304 H/S30409	0,10*	19,0	9,5	—	—	490	200	45
	VLX 304 L	Z 2 CN 18.10	1.4306	304 L/S30403	0,03	18,5	11,0	—	—	470	175	45
	VLX 321	Z 6 CNT 18.10	1.4541	321/S32100	0,08	18,5	10,5	—	Ti > 5C < 0,6 %	490	190	45
	VLX 321 H	Z 8 CNT 18.10		321 H/S32109	0,10*	18,5	11,0	—	Ti > 4C < 0,6 %	490	190	45
	VLX 347	Z 6 CNNb 18.10	1.4550	347/S34700	0,08*	18,5	11,0	—	Nb > 10C < 1 %	490	200	40
	VLX 347 H	Z 8 CNNb 18.10		347 H/S34709	0,10*	18,5	11,0	—	Nb > 8C < 1 %	490	200	45
	VLX 316.2	Z 6 CND 17.11	1.4401	316/S31600	0,07	17,0	11,5	2,25	—	490	190	45
	VLX 316.3	Z 6 CND 17.12	(1.4403) 1.4436	316/S31600	0,07	17,0	12,0	2,75	—	490	190	45
	VLX 316 H	Z 8 CND 17.12	1.4919	316 H/S31609	0,10*	17,0	12,5	2,50	—	490	190	45
	VLX 316 L2	Z 2 CND 17.12	1.4404	316 L/S31603	0,03	17,0	12,0	2,25	—	470	175	45
	VLX 316 L3	Z 2 CND 17.13	1.4435	316 L/S31603	0,03	17,0	12,5	2,75	—	480	175	45
	VLX 316 Ti	Z 6 CNDT 17.12	1.4571 1.4573		0,08	17,0	11,5	2,25	Ti > 5C < 0,6 %	490	190	45
	VLX 317 L	Z 2 CND 19.15	1.4438	317 L/S31703	0,03	18,0	14,5	3,50	—	520	220	40
	VLX 309	Z 12 CN 24.15	1.4833	309/S30900	0,15	25,0	14,0	—	—	515	205	30
	VLX 310	Z 12 CN 25.20	1.4845	310/S31000	0,15	25,0	20,0	—	—	540	240	30

* 0,04 ≤ C ≤ 0,10

* Designations in brackets are approximate

Figure 1b : Grades of Stainless Steels Available from One Supplier.

Figure 2 : Input for Heat Trace Program

- Project Name : Steam or Electric
- Maintain Temperature : 250 F
- Total Pipe Length : 200 ft
- Exchange Rate : Foreign currency
- Labor Rate : 20.00 \$/h
- Electricity Cost : 0.0600 \$/kWh
- Steam Cost : 5.00 \$/1.000 lb
- Steam Pressure : 150.0 psig
- Steam Tracer type : Copper, ½ in
- Max Steam Tracer Length : 200 ft
- Time Pipe is Flowing : 80%
- Time Tracing Required : 12 months
- Average Ambient Temperature : 50 F

Figure 3 : Specifications for Welding Outlet Flanges

- System Pressure/Temperature Design
- Design for Reliability
- Dynamics of System Failure
- Thermal Fatigue
- Nondestructive Examination Requirements
- Stress Intensification Factors
- Stress Indices
- Flexibility Characteristics
- Line Flow Velocities
- System Corrosion Allowance
- System Service Life vs. Total Plant Life

Figure 4 : Supplementary Requirements, Welding Flanges
ASTM-A105-81 Supplementary Requirements

- S1 Macrotech Test
- S2 Product Analysis
- S3 Hardness
- S4 Tension Tests
- S5 Magnetic Particle Examination
- S6 Liquid Penetrant Examination
- S7 Hydrostatic Testing
- S8 Repair Welding
- S9 Heat Treatment
- S10 Marking Small Forgings
- Chemical Requirements
- Permissible Variations in Product Analysis
- Mechanical Requirements

Figure 5 : Items to Check for in Manufacturer

- Forging and/or Casting Ability
- Machine Tools Used
- Quality Control Procedures
- Inspection Procedures
- Equipemt Used in Manufacture
- Heat Treatment Capabilities
- Material Identification Procedures
- Packaging and Protection Procedures

How comfortable would you be assuming these responsibilities? Not very I think, because they really fall within the province of the mechanical engineer.

The point of all this is that few, if any, teachers of design courses are going to have many of such details available. Not to deal with such items is to mislead the students and leave out many things about plant design that they need to know. For this reason I tend to the position that design as such should be left to the post-graduate engineer in his industrial position.

The courses I have seen in project design were similar to those outlined for plant design except that the end result is a pilot plant scale or bench scale operating unit. In many instances projects are selected on the basis that they would benefit the local or surrounding economy of the institution. The team approach is frequently used and the aim of the year-long project is to develop an operating small-scale or pilot plant. In most departments resources are limited so the project frequently becomes merely an endurance contest of trying to go find something that can be operated a short while to produce a little bit of the product. University purchasing times are such that very little, if any, new equipment can be ordered and received in time to benefit the project. Vendors as sources of good information are almost non-existent. They are interested in education but the prospect of a sale does not exist and the time and effort devoted to answering student inquiries usually is not very great. The vendor is sort of like a faculty member who frequently receives a request from a student for "all of his publications and references" in some given area. In my own case I have about three or four file drawers full of references on gas sweetening and I can assure you that I do not have the secretaries reproduce those each time I receive such a request. My experience is that vendors avoid spending much time and effort where prospects for a sale are slight.

This means that the students in a project engineering course may be exposed to some discussion of the many aspects of plant design as applied to the subject matter of their project, but they do not have very meaningful exposures to any of these areas. This to me represents a serious and drastic shortcoming to project design as used here.

Process design involves selection between alternative processes by which the same end product(s) can be made. It can be taught as a rather detailed analysis of one fairly involved process with the students working for a semester or perhaps even a year on the single process. Alternatively, it can be taught as a series of shorter problems each covering new aspects of process design and selection. Students may be required to work individually or perhaps can be allowed to work as a team.

Of the four possible types of design experience that can be made available to students in chemical engineering I strongly favor the process design approach. The information necessary for utilization of this is more likely to be available among present day faculty members than is the background to teach either plant design or project design. The adaptability of the process design to shorter problems gives the students the advantage of the preparation of several design reports during the design course. While students may not view this as an "advantage", it truly is. Writing is much like speaking or any other activity - practice tends to make perfect. Learning how to write reports is an integral and necessary part of the design experience.

An integral part of design is cost estimation. By and large I favor the use of estimating procedures which emphasize estimating the cost of major process equipment then using accepted factors for such things as fabrication, piping, instrumentation, etc. The detailed estimate of the cost of a fractionating column involves many items of information that are not normally available in a classroom situation. Preparation of a cost estimate of a plant (approximately ± 25%) is a realistic thing to expect from a classroom exercise in process design.

The use of "teams" in design is worthy of comment. From the standpoint of the teacher of the course there is a tremendous incentive to use teams -- the number of reports to be graded is decreased by a factor of three or four. I have never been able to develop a satisfactory approach to making certain that each individual in each team does a representative share of the assigned work. On the contrary my experience has been that the best student in the group tends to become overworked either because the other students want to "ride" on his efforts or because that student has the most pride in obtaining a good grade and therefore is willing to do the work of the others. At any rate, I strongly favor individual assignments rather than team or group efforts on problem solutions.

To those who argue that industry uses design teams my reply would be that the team probably does not consist of only Chemical Engineers. Rather the team has representatives from the various technical areas that will be required to put together an acceptable plant design. If we could put together a team with experts in mechanical design, instrumentation, corrosion control, etc., my feelings might be different.

No discussion of design would be complete without mention of digital computers and process simulation. I first became involved with digital computers in the summer 1955. Oklahoma State has routinely used them in design classes since about 1957 or 1958. In the early days computers were relatively simple to involve in the design course because the calculations carried out on the computer were essentially the same as those that would have been done by hand. This made an easy progression where the students first did a calculation at least one time by hand and subsequent required calculations of alternates were carried out by use of the computer.

Today this has changed and the computer algorithms used for solution of process problems bear no resemblance to the type of calculations one would do by hand. However, this does not, in my opinion, eliminate the desirability of having students know shortcut estimation procedures that can be used to check computer results. As a matter of fact, there may be even greater need for those shortcut checks today because so many times there is little or no intervention by the engineer into the design calculation process.

As main frame computers become larger and faster, process programs became larger and more complex. This caused the design engineer to become more withdrawn from the solution of his problems. This reached the point that the engineer was doing little engineering of his design if, indeed, he did any at all. This is understandable because of the way engineering courses are taught. Most students think they are doing engineering when they perform calculations. This is not true at all. The engineering is done before the calculations start: if it isn't done then, very likely there will be no engineering done.

When personal computers first became available my anticipation was that we would once again return design to the engineer. Before that could happen the desk top computer became so powerful that they are now capable of carrying out a full scale process simulation in a matter of a relatively short time. While this offers advantages it also offers tremendous disadvantages. A person can sit down at a computer console, input a bare minimum of information, give completely unreasonable estimates of various parameters, and achieve a closed solution that appears to satisfy heat and material balance requirements for the process. This is just fine except for one thing. From my standpoint of view I do not believe that a preprogrammed computer solution can provide the ingenuity and creativity that is desirable and necessary in most process designs.

One major company goes so far as to require that there be "defaults" for every item of required input. All a person has to know is to hit <enter> or <carriage return>. The result will be a process designed entirely on default values. This is engineering?

One of the real challenges in teaching process design in today's world is to provide the student a learning experience that will not only provide him with an understanding of the calculations that the computer has made but equally, or more importantly, will give him the beginning of a set of guidelines for evaluation of computer results to see that they are reasonable. Should the distillation column be 2 feet in diameter or 12 feet in diameter? Should the compressor require 100 horsepower or 10,000 horsepower? No computer program is perfect. All of them require careful analysis of the results of their many calculations to make sure that the results are reasonable and give some hope that the process unit will operate satisfactorily.

I listen with concern and discouragement as my industrial friends discuss the programs that they use. Seldom, if ever, is the matter of program accuracy and reliability of results mentioned. Rather the emphasis is on how easy the programs are to use and the speed with which results can be obtained.

The computer exists. It will sit on the desk of the young graduate once employed in industry. The challenge for all faculty members in Chemical

Engineering, but particularly those teaching process design, is to make sure that their students know how to properly use the computer and the programs available to achieve accurate, reliable results. There is an old saying "GIGO" - garbage in, garbage out. Several years ago one of my students graduated and went to work for a major petrochemical company. He authored a report based on a study he conducted for the possible major expansion of the company position in a given chemical. The report was read and praised by a number of people. Eventually it reached the desk of an old line individual who was vice president of the company. I am positive that this man had no capability at all at computer calculations but he did know the business. He said succinctly "It (the report) is wrong". This caused a good deal of consternation and also a great deal of searching to determine what the problem was. One of the key input cost parameters for the chemical had the digits reversed. There is a great deal of difference between a raw material cost, for example, of 15 cents per pound and a raw material cost of 51 cents per pound. I know that I had done everything in my power to impress on that young man the necessity for very carefully checking, and cross-checking, and recross-checking of input data to a computer program. He still failed to do it when it really counted most.

A very real problem that exists in using computer simulation programs is accuracy of solution. Difficulties can arise in making any given type of calculation. In general the programs available today print few, if any, warning signals about difficulties being encountered. This is primarily because the engineers using the program would not understand what the warnings meant and would be confused by them. They might even go so far as to think the program had no value. This makes even more important the availability to the student of hand procedures and background information to evaluate computer solutions for feasibility and probable accuracy.

Confidence in the program you are using is not enough. While preparing this lecture, I used a tray-by-tray distillation program that is essentially the same that I have used for some twenty or so years and for as many as 500 tray-by-tray calculations, at least 50 for condensate stabilizers. The results for the stabilizer were wrong! Had I accepted the "converged solution" the operating tower certainly could not have produced the predicted product streams.

Figure 6 shows the schematic flow diagram and feed stream for a typical natural gas compression train (11). The conditions are what might reasonably be expected in any such installation. Four widely used calculation procedures were used to compare calculation results. Two predict the outlet product will be a gas; two predict the product will be liquid. Which is correct? Build the plant and find out.

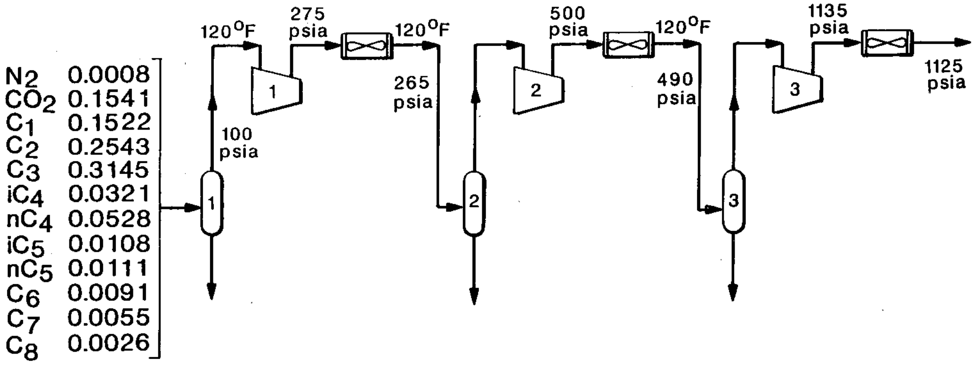

Figure 6 : Three-Stage Compressor with Interstage Coolers.

One of the great problems in teaching process disign to chemical engineering students is maintaining faculty competence in the area. If I had taught in my last years of teaching the same things that I practiced when I was employed full time in a design capacity in 1951 and 1952 the students in my classes would have gained little. The teacher of process design must find an avenue to keep abreast of practices in industrial applications. There are a variety of ways in which this can be done. The important part is that it must be done if the design course is to have maximum value to the students in it.

A few years ago I had an interesting discussion with a young surgeon who had been appointed a Director of the OSU Foundation and as a result became very interested in "education". I was discussing engineering and the fact that engineers must practice what they teach. As an example, I said that I would not care to have my body 'whittled' on by one who had only studied the theory of surgery, even under the most outstanding surgical theorists in the world. He, of course, agreed enthusiastically. When I suggested that neither would I care to invest money in a plant designed by one who has only studied the theory of design, he demurred - "It isn't the same thing". I maintain surgery and design are exactly the same in this regard - mastery of the theory is not enough. There must be practice under the supervision of a 'master' before one can become accomplished in the art.

The only way to gain and maitain competency in process design is to practice it. This must be done in an industrial environment where it is "real". In a city like Houston or Philadelphia this is relatively easily done. In a city community like Stillwater, USA it is much more difficult. For the faculty member, there will necessarily be absences from the campus. In contradiction to policies at Oklahoma State, being in class every day is not the most important thing for a Chemical Engineering faculty member. Incomplete or incorrect information is more harmful to the student than no learning.

I can make no reasonable argument for a Chemical Engineering faculty member selling insurance, being a real estate agent, owning a farm, or running cattle. I can make a forceful case for those faculty practicing for industry the skills and knowledge that they are trying to transmit in the classroom. That they are paid consultants is incidental. The important thing is that they are practicing what they teach. There is no place today for the saying "Those who can do, and those who can't teach."

As Chemical Engineers, our world is not composed of closed anlytical solutions. The universities must accept this and encourage faculty to obtain real life design experience on a continuing basis.

To briefly summarize this lengthy discourse my suggestion for teaching design in chemical engineering are:

(a) Teach process design.
(b Use a number of short problems as opposed to one year-long problem.
(c) Require individual student problem solutions for at least most of the assignments.
(d) Make the students use the digital computer frequently.

(e) Do everything in your power to make sure the students use the computer intelligently.
(f) Make certain that at least a few of the problems involve cost estimating tenhniques.
(g) Work hard at developing and maitaining faculty competence to teach a meaningful design course.

If these suggestions are followed my belief is that you will do the best job possible of preparing students for entry into chemical engineering jobs after graduation.

REFERENCES

1. **X, Professor,** This Beats Working For A Living, Arlington House, New Rochelle, New York, 1973.

2. **Lewis, W.K.** and **A. Radasch,** Industrial Stoichiometry, McGraw-Hill, 1926.

3. ____________, "Criteria for Accrediting Programs in Engineering in the United States," Accreditation Board for Engineering and Technology, Inc., New York, December, 1987.

4. **Maddox, R.N.** and **J.B. West.** "A Professional Program in Engineering," Chemical Engineering Education, p. 66, Spring, 1973.

5. **Zimdahl, Robert L.,** "Research and National Defense," Journal of Irreproducible Results, p. 23, July-August, 1988.

6. **Douglas, J.M.** and **R.L. Kirkwood,** "Design Education in Chemical Engineering," Chemical Engineering Education, p. 22, Winter, 1989.

7. **McCready, J.M.** "An Alternative Approach to the Process Design Course," Chemical Engineering Education," Spring, 1989.

8. Valinox Advertisement, Hydrocarbon Processing, November, 1988.

9. **Sandberg, C.** "Heating Tracing: Stream or Electric?", Hydrocarbon Processing, March, 1988.

10. **McGuiness, W.N.,** "Welding Out Fittings," Hydrocarbon Proceesing, November, 1988.

11. **Lilly, L.,** "A Review of Process Simulation Software," Gas Processors Association Permian Basin Regional Meeting, May 4, 1989.