

AC 2007-113: EFFECTIVE TEACHING AND LEARNING IN CHEMICAL PROCESS ENGINEERING DESIGN

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Effective Teaching and Learning in Chemical Process Engineering Design

1. Introduction

Before the age of electronic calculators, mainframe or personal computers, engineers could design many of the structures and plants we see today. Perhaps these structures and plants were not as optimized as those we might be able to design today with all our modern computer design aids. However, what is clear is that senior engineers could not be competent in design without a solid grounding in the engineering fundamentals. Today it may be possible for graduates to use modern computer aided design programs and achieve an adequate design without a good understanding of the engineering fundamentals involved. If their assumptions and operation of these modern software design tools are correct all is well. However without a good understanding of fundamentals they may not realize when an incorrect answer is produced. The old saying of garbage in, garbage out is even more relevant today!

Those who teach design face the dilemma of needing to teach “old fashioned” equipment design methods so that students will understand the fundamentals and also attempt to teach modern computer aided design techniques, knowing that most design engineers, who work for large corporations may never use these “old fashioned” design methods again in their working careers and will rely heavily on modern computer technology. However, this is an environment where smaller organizations are probably different.

Should we abandon traditional design methods and just teach modern methods or should we try and pack both into already overloaded courses? The authors propose that students must get an appreciation of both traditional and modern design methods in some areas of design and must be taught the importance of fundamentals. Above all else they must know what they do not know and be prepared to work to understand both the fundamentals and modern computer aided tools in their future work. A computer-aided design is of little value if one cannot use judgment to verify the reasonableness of the answer using first principles. The learning objectives are to provide young design engineers with competency in both the older fundamental design approaches and more modern computer-aided design techniques. In addition, to understand the limitations and challenges of both approaches and then decide on the most appropriate technique in different circumstances.

The approach is exemplified by reference to the applicants greater than fifty years combined teaching and practical design experience and courses at The University of Auckland and the University of Calgary. The paper continues with some motivating/typical examples before describing the course pedagogies /philosophies and then individual course structures. Student evaluations of the approach as applied in both of these programs are presented and discussed.

2. Some Motivating/Typical Examples

In all refinery crude units a small amount of light gas must be separated from the naphtha and heavier products. While some butanes usage is possible for gasoline vapour pressure control it is

common for propane and most of the butanes to be sold as LPG unless the refinery has a unit that upgrades these materials into more valuable products. While many side strippers on crude units have indirect heat sources it is still common for some live steam to be used to assist in stripping in the crude unit. Downstream processing of these light gases must recognize the presence of water and must manage this component.

In one refinery after light gas removal and amine treatment the overhead gases were sent to a depropaniser which made the local spec for LPG as a bottoms product. This stream was then sent to a mole sieve unit to remove the water from the LPG product prior to storage and marketing. Capacity upgrades on the crude unit were not accompanied by comparable upgrades in the LPG production system and LPG specification problems resulted.

Junior chemical engineers were assigned the troubleshooting of this problem and decided as a first step to develop a simple computer process simulation of this unit. A four component system was considered adequate with propane, iso-butane, normal butane and water. The bottoms stream was butane rich with primarily propane in the overheads. With cooling water on the overheads of the depropanizer the overheads pressure had been design to provide an acceptable delta T vs the cooling water temperature. The bottom temperature of the column was at a higher temperature reflecting the higher butane content. Initial results from the simulation showed what appeared to be satisfactory operation of the depropanizer. However plant analysis indicated that the LPG drying unit was being overloaded and the water content of the LPG was off spec.

Should the junior engineers have taken a different approach? Was this a case where the power of the process simulator was assisting or hampering their troubleshooting analysis? The young engineers had not gone back to review the operation of the crude unit at higher capacity even though it was well above the original design basis. This new mode of operation of the crude unit was causing increasing problems with achieving naphtha and kerosene specs and more steam was being used in the side strippers. The water content of the LPG being fed to the depropanizer had obviously increased. The young engineers had the feed composition going to the depropanizer and an approximate mass balance based on plant data. Could the problem have been analysed without a detail process simulation of the depropaniser column? A simple hand calculation revealed that the maximum quantity of water that could be carried out the top of the depropanizer tower, based on the water partial pressure at the top temperature of the tower, was less than the water entering in the feed vapour. The temperature at the bottom of the tower indicated all the water could exist in the vapour phase at the bottom of the tower. Clearly a second water phase was being formed inside the tower which was having adverse impacts on downstream LPG drying and hence product specification. This problem occurred more than fifteen years ago where many process simulators had considerable difficulty in managing water and hydrocarbons¹. More modern simulators may provide warnings about this type of situation e.g. VMGSim². However the more important observation is not whether the simulator provides warnings but whether junior engineers construct a detailed computer model of the apparent problem area prior to actually reviewing the first principles operating data to see if a fundamental understanding of the changed conditions can be developed without simulation.

The tendency of modern students in chemical engineering to rush into developing a detailed computer model of their proposed process before they have thought through the fundamental

engineering principles involved is further illustrated by the University of Auckland fourth year design project assignment for 2006. The students were taken on a class trip to visit a methanol production facility. Having visited the plant they were provided the PFDs for the methanol distillation area (a typical a topping column to remove lights followed by a single refining column operating just above atmospheric pressure to separate methanol overhead, water in bottoms and ethanol in the fusel oil side draw) and asked to develop a simulation to match the actual column operating data for the refining column. Methanol/ethanol/water requires some care in choosing thermodynamic properties to ensure a reasonable match between predicted and actual reflux ratios and theoretical trays. Most students achieved a moderate match, but many students still struggled to understand that the actual as measured operation of the distillation unit was the real answer rather than the computer simulation predictions.

The next phase of the final year design assignment was to consider alternative methanol distillation designs which might improve the sustainability by reducing energy consumption. After some review and discussion most students understood that the single refining column could be split into a high and low pressure column with the overheads of the high pressure column driving the bottoms of the low pressure column. In this way overall heat input could be reduced, although higher grade heat would be required in the high pressure column reboiler. Having understood the concept of a high pressure/low pressure refining column arrangements the students were given an assignment to develop a computer process simulation for this two column design based on the information they had developed already on how to manage the vapour liquid equilibrium (step #1). Deliberately, no guidance was provided to the students as they attempted this portion of their final year design. The class was split into twelve groups and all groups submitted their process simulations on time. As expected, but perhaps rather disappointingly, no groups had recognized the need to develop a proper pressure profile of the two column system prior to starting their simulation. As a consequence the incorrect pressures on the top of the high pressure column and bottom of the low pressure column gave all groups an invalid reboiler/condenser design and the incorrect reflux ratio versus number of trays point because of inaccurate tower pressure. Step #2 was thus to develop a proper pressure profile for the entire system, with step #3 being to redo the entire simulation.

Why do junior/modern chemical engineers/students rush to the computer when a short period of real thought and some scratches on a piece of paper would have saved time? Perhaps more senior engineers who grew up before substantive computing power existed did not have a choice but to think about the problem before attempting tedious hand calculations. It is clear that modern chemical engineers have a far greater degree of comfort with computational techniques and that this has the potential to make them more productive engineers. The trick seems to be to teach the current generation that a little thought is worthwhile before they charge ahead and that the computer results are not always accurate. VLE and thermodynamic data are as much a challenge today as they were thirty years ago.

3. Pedagogy/Course Philosophy

An open-ended approach is recommended to teaching process design³. Through the use of active, hands-on or resource based learning techniques^{e.g. 4, 5}, student learning takes place through projects⁶. From a learning perspective, a limited number of lectures to motivate students

rather than to transmit information and a majority of “hands on” projects is advocated. The general course philosophy is “learning through doing”, that was perhaps best articulated in the following statement by Benjamin Franklin⁷:

“Tell me and I forget,
Show me and I may remember,
Involve me and I understand”

With respect to the teaching of computer-aided process design, tools such as VMGSim² are made available to the extent possible. However, hand calculations are done first and strongly encouraged subsequently, as described in section 2 of this paper. Students must be made to take responsibility for their results.

4. Course Structures

The details of individual course structures will of course vary according to the resources available to the Department. A two semester final capstone course is recommended^{3,8}, divided essentially into PFD-level preliminary process design with $\pm 25\%$ economics and a P&ID-level detailed design to $\pm 10\%$ economics. Figure 1 illustrates the typical components of process design with particular reference to the University of Calgary courses.

4.1 University of Calgary Process Design Course

Calgary has the luxury of many academic mentors with process design experience that can mentor individual groups. Therefore groups of 3-4 students can work on different process design projects of varying difficulty. Calgary also has strong links with a strong local industry and a large number of local engineering companies. Some projects are facilitated by industry. Some projects are jointly mentored by industry. The projects for 2005-2006 are listed in Table 1.

Table 1. University of Calgary Process Design Projects 2005-2006:

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| <ol style="list-style-type: none">1. Erythropoietin Production2. Propylene from Propane3. Ethylene from Methane4. Sulfuric Acid from Hydrogen Sulfide5. Methanol from Methane6. Vinyl Chloride from Ethylene and Chlorine7. Sour Gas Sweetening with 2 tonnes/day Sulfur as 1% Hydrogen Sulfide8. Low BTU Gas Production with Nitrogen Removal9. Flexible Cryogenic Hydrocarbon Liquids Recovery10. Bio Fuel Ethanol Production11. Tar Sands Asphaltene / Coke Gasification to Produce Hydrogen12. Ammonia Production |
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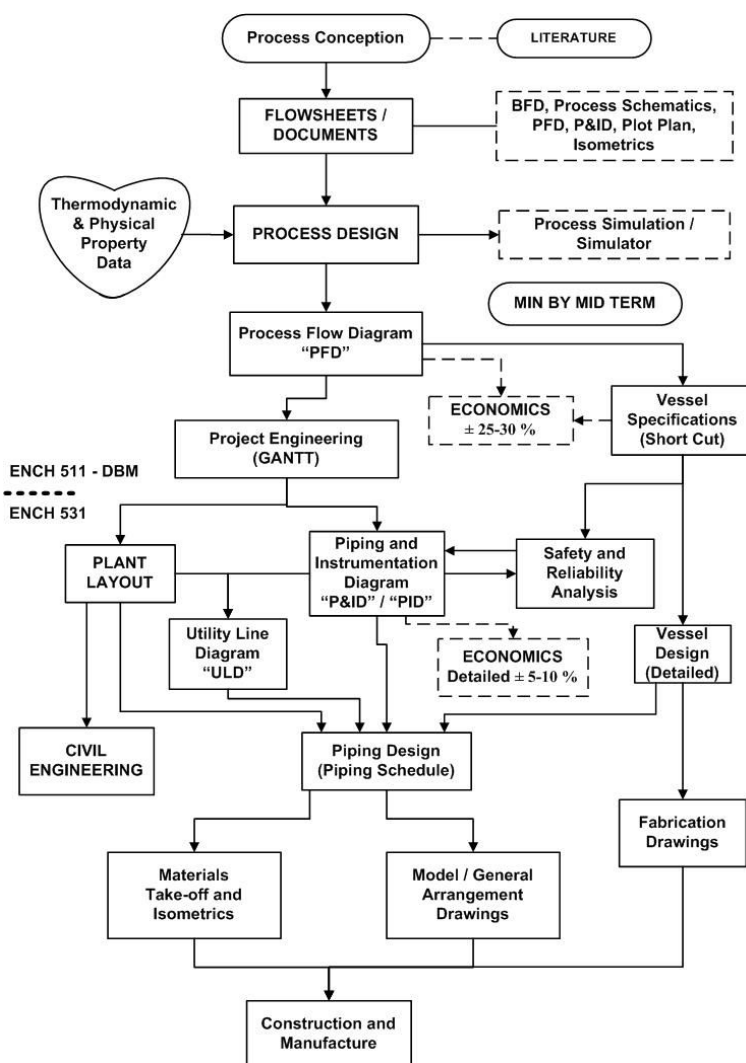


Figure 1. Process Design Overview (with University of Calgary Courses as indicated).

A combination of written and oral reporting is employed for assessment. The first task for each semester is a short mid semester progress report (6 pages) and 15 minute presentation. Then individual, 8 minute in-class presentations at the end of each semester. The final assessment for each semester is the project report (binder). For the final semester the students also make a final 45 minute public group presentation to industry at the end of the examinations period.

4.2 University of Auckland Process Design Course

Auckland has only two academics with process design experience. Therefore groups of three or four students must work on variations of the same design project. For example, in 2005 the project was Methanol from Syngas and the variations were in syngas composition and pressure. In 2006 the project was the Methanol Distillation Revamp as described in section 2 of this paper and the students proposed their own designs for reducing energy consumption.

A combination of written and oral reporting is again employed for assessment. Assessment tasks included: preliminary BFD by hand (mid semester 1); mass and heat balance and preliminary PFD both by hand quickly followed by a PFD review (mid-end semester 1); preliminary submission and group progress interview (end semester 1); process simulation, revised PFD and initial P&IDs (mid semester 2); final design report (end semester 2); final individual interview and peer review (end of semester 2).

5. Student Evaluations

The open-ended approach described has been implemented and evaluated since 1975 at Calgary and more recently at Auckland. Most student feedback upon graduation is that the course is a lot of work, but they learned a lot; Working in groups not always pleasant; Oral presentations and short/long reports are great; Most student feedback a few years out is that design is the best and only course they remember and their final report is still on their office shelf.

6. Conclusions

- i. A open ended approach is recommended for modern process design education
- ii. Two open-ended approaches at two different schools are described
- iii. Computer aided process design is facilitated – but students are made responsible for their results
- iv. Students do learn by doing!

We also recommend that a design program should include the following elements:

- v. An active learning approach in chemical engineering design
- vi. A real challenge to the student in the form of an open ended problem
- vii. Oral, written, organizational and team skills – i.e. real life skills

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