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An Honors Capstone Design Experience Utilizing Authentic Industrial Projects*

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The Design Internship in Pollution Prevention at The University of Tennessee is an honors capstone design course in which source reduction is incorporated into the design of industrial processes. In this activity pollution prevention through basic flowsheet development and equipment selection is emphasized rather than conventional treatment of the effluent waste streams. This activity was begun in 1990 and has involved 128 students and 32 projects. The number of projects per year has varied from 1 to 8. The output of each of these activities is a design report. An important benefit of these activities is an intensive process design experience for the students that emphasize pollution prevention concepts. The paper summarizes accomplishments and lessons learned.

INTRODUCTION

The Design Internship in Pollution Prevention at The University of Tennessee has been active since the late 1980s (1–4). Sustaining support for this activity has come from the DuPont Company; DuPont has been joined by a number of other corporate sponsors including Dow Chemical Company, Aquafortis Engineering, Federal Mogul, Rohm and Haas and Oak Ridge National Laboratory. Each student design team is supported by a faculty and an industrial advisor (coaches). The emphasis on source reduction in this program is consistent with responsible commitment to environmental excellence. This commitment guides the following priorities. (1) The design of processes will emphasize technology selection such that all process materials are converted into useful products; to the extent that all process materials are unsuccessfully converted, the remaining design priorities will be (2) recovery and recycle of all materials; (3) material that must be put into the environment will be in a form that is transparent to the environment and (4) failing all of the above, material will be put in a form that is safe to handle, immobilized and securely stored in a controlled manner. Utilizing that philosophy, internship projects in process design have completed studies on far-ranging topics, including:

- design of future facilities for production of adipic acid;
- recovery of catalyst in organic chemical manufacture;
- design of a facility for the recovery of antifreeze constituents;
- design of wastewater treatment facilities;
- evaluation of techniques for industrial water reus;
- future systems for the production of HCN;
- recovery of and reuse of purge materials from adipic acid production;
- treatment of sludge from biological wastewater treatment reactors.

This activity is offered as Chemical Engineering 488 and entitled 'Design Internship in Pollution Prevention', and is now a permanent component of the curriculum, a 3-semester-hour alternative to the traditional senior capstone design course. All projects culminate in a final presentation to the industrial sponsor and preparation of a reviewed final design report.

The design internship proceeds through some typical steps leading to preliminary process synthesis and evaluation:

- project selection
- group membership selection
- project initiation
- feasibility study
- narrowing the field of alternatives
- preliminary design report and presentation
- flowsheet development
- estimation of capital and operating costs
- selection of most promising alternative(s)
- final report and presentation.

The function of the faculty and industrial advisors is to primarily provide coaching, advice, project review, and to insure quality and accountability.

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CAPSTONE DESIGN EXPERIENCE

This project is one of a few academic experiences involving a team rather than an individual effort. The students have typically had limited exposure to environmental regulations or waste management operations. Students typically alternate weekly as group leaders, who communicate frequently with their advisors. Three hours per week of scheduled group meetings with their faculty advisors present are typical; in these meetings, goals are formulated, accomplishments presented and reviewed and a few supplemental faculty lectures are presented. The students contribute a great deal of time to successful conclusion of these projects, similar to that required of a typical engineering capstone design experience.

Project selection

Discussions within DuPont begin several weeks in advance of the initiation of the project, with the faculty advisors typically involved in the final selection of the project; the selection criteria are based on their educational benefits, value to DuPont and on the possibility of being completed in one semester. One or more DuPont personnel volunteer to function as industrial advisors for the students.

Group membership selection

The students are selected based on their academic achievements and completion of an informal interview. Providing equal opportunity for all chemical engineering students having appropriate prerequisite course work is an important consideration. Groups of highly motivated and cooperative individuals produce noticeably higher quality results than groups where these characteristics are lacking.

Project initiation

Various formats for project initiation have been utilized. In earlier projects, the initiation occurred at a production site where the facility was toured; later projects have been initiated on campus, sometimes with a visit from the corporate sponsor. In the initiation discussions, production information is provided and the ground rules for the project established. Sometimes alternative designs are suggested in the initial meeting and supporting information provided, as available; still other alternative designs are developed by the students later in the study. The supporting information includes desired product purity, relevant reaction rates and yields, reaction and phase equilibria information, by-product formation data, operating and pilot plant data, and safety and toxicity information; it is common that more supporting information be available for some alternatives than for others.

Due to limited travel budgets and minimal travel time available to the students, the current project initiation generally occurs on campus. When the students visit the related production facility later in this activity, they are more knowledgeable about the facility and perhaps gain more from their visit than otherwise. It is typical for the students to visit and present a briefing at the conclusion of their feasibility study or later in this activity when flowsheeting is complete and capital and operating costs are known. Briefly, attendance generally includes industrial and faculty advisors as well as interested industrial personnel.

Feasibility study

The feasibility study provides information on the appropriate design alternatives. It insures that the students have the necessary information to make their own decisions as to appropriate technology. A computer search of the literature greatly expedites this project phase. There is often extensive communication between the students and industrial project advisors via e-mail, FAX messages, and telephone conferences; video conferences are more expensive but still lower in cost than personal visits. The combination of FAXed documents, speaker phones and conference calling provide low-cost and effective means of communication involving a number of people at different sites. At the conclusion of the feasibility study, the students present and discuss their findings with the corporate sponsor; these are important discussions in insuring that the objectives of the design study are being met and that all feasible options are identified.

Narrowing the field

At the conclusion of the feasibility study the alternatives are screened to ensure that the most appropriate options are considered. The students are encouraged to develop screening criteria that properly emphasize DuPont's hierarchy of waste management priorities. At this phase in the project, material and energy balance flowsheets have not been developed and no capital and operating costs have been determined. The results of these screening steps are typically presented to the corporate sponsor simultaneously with feasibility discussions.

Preliminary design report and presentation

The result of the feasibility study and the alternative screening step are provided in the forms of an oral and a written report. The written report spreads the report writing tasks over a greater portion of the semester than would be the case if only a final report were required. Essentially all of the material in the preliminary report will become part of the final report. The preliminary report and all sensitive communications may be treated as business confidential; for some projects, students sometimes sign a 'limited term' secrecy agreement with DuPont. Faculty are covered under more inclusive secrecy agreements.

Flowsheet development

Identifying waste streams in the early stages of process design is expedited by considering waste streams to be intrinsic or extrinsic. Intrinsic waste streams are those that are inherent to the process configuration while extrinsic waste streams are those that are associated with the operation of the process [2]. Some waste streams may be identified from the macroscopic material balances; identification of waste streams not apparent in the macroscopic material balance may be difficult at an early stage of process development. Identification of intrinsic wastes may, at times, require experimental data; identification of extrinsic wastes usually requires experience. A great deal of the nature and the input/output structure of alternative flowsheets [3] may be found from an examination of the reaction step. Information on some waste streams requires discussions with knowledgeable DuPont personnel in order to get a total view of the wastes generated in an operating process. This designation of waste streams is discussed further in [2].

The window for creativity in these activities comes after the students understand the process and its constraints and are formulating their flowsheets. The semi-structured brainstorming activities of the flowsheet formulation phase may take a considerable amount of time but are critical for the opportunity they offer for creativity.

Estimation of capital and operating costs

For preliminary estimates of fixed capital investment by persons other than an expert, the factored approach has generally proven reliable and is generally the method selected. In this method of cost estimating, the purchased cost of the major equipment items is estimated (usually using published costing information) and the total fixed capital investment is estimated by applying a multiplier (Lange factor) to the purchased cost of the major equipment items [4]. When time for this activity has been compressed, an approach has been utilized based on an method by Zevnik and Buchanan [5]. This method must be carefully applied, however, and calibration of the procedure using actual cost data is recommended. Specific operating cost information, product and raw material costs, are consistent with those used within DuPont.

Selection of most promising alternative(s)

Selection of the most promising alternatives occurs when capital and operating estimates have been completed. Again, the students are encouraged to develop criteria that properly emphasize DuPont's hierarchy of waste management options as well as cost and other considerations. In chemical engineering design, the selection of the most promising alternatives usually leads to higher levels of design activity with tighter focus and increasingly definitive information.

Final report and presentation

The final design report from this activity is a business confidential document; as mentioned earlier, students typically sign a 'limited term' secrecy agreement with DuPont. The agreement to hold findings of these projects and related information secret is important if the students need access to proprietary information in order to provide a useful study. The final report is reviewed first by the university advisors; after these comments are addressed, the report is reviewed a second time by both university and DuPont project advisors. A final oral report is also made by the student design team at the conclusion of the project.

CONCLUSIONS

The type of activity described here provides for involvement of university students and faculty in significant and challenging projects involving pollution prevention. The expected benefits to the students participating in these activities are:

1. Development of solutions to existing chemical engineering problems proceeds under realistic industrial considerations and tight time constraints.
2. Students experience group problem-solving where they establish their own group structure and assign their own responsibilities for the results.
3. Students are faced with the development of flowsheets and material balances while having very incomplete process information.
4. The studies emphasize pollution prevention through basic process flowsheet and equipment modifications rather than through conventional waste effluent treatment applications.

The successful completion of projects such as this supplements corporate design activities, particularly when emerging technologies are involved. This project and similar activities have been well received by the students; their enthusiasm, perseverance and overall quality of work are sincerely appreciated by their advisors and sponsors. Participants in these activities typically begin industrial careers soon after project completion with a smaller number going to graduate school.

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