Session 1313

A Traditional Material Balances Course Sprinkled with "Non-Traditional" Experiences

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SUMMARY

The traditional "first course" in most Chemical Engineering programs is the Material and Energy Balances sequence, typically taught in the sophomore year. In the introduction to their text, "Elementary Principles of Chemical Processes", Felder and Rousseau make the following observation: " A criticism sometimes leveled at the stoichiometry course is its emphasis on drill and routine solution methods, an emphasis that gives the student little idea of the wide range of problems to be encountered by the practicing engineer and the imaginative and creative abilities needed to solve some of them. Unfortunately.....the only way we have found to teach students the engineering approach to process analysis is to have them practice it, repeatedly, until they get it."

From their assessment it appears that the challenge facing the instructor is to provide sufficient "practice" at problem solving to make the students proficient, while providing sufficient additional stimulus to keep the students excited about chemical engineering. We have addressed this challenge in our Material Balances course by providing the students with a quarter long project based on a an actual chemical engineering process. The process that has been used for the past three years is the Ford-Wixom Material Balances Multimedia Module developed by Prof. Susan Montgomery and co-workers in the Multimedia Engineering Laboratory (MEL) at the University of Michigan.

There are several unique aspects to the project which separate it from routine course work, while providing a solid grounding in material balances and problem solving. The students are divided into groups of three "project engineers" and are assigned to a "group leader", who is typically a junior or senior chemical engineering student (Note: The upper division students participate in a 1 cr. Leadership and Mentoring course which is described in paper 2213-03). The "chain of command" that is established is similar to that the students will encounter in industry, with the instructor as the "project director", the upper division student as the "group leader", and the students as the "project engineers". The problem is assigned by the "project director" with a specific timeline given for completion of tasks. It is made perfectly clear that the "group leader" is there to provide guidance, assign tasks to individuals, and review work, but that the actual material balance calculations are the sole responsibility of the "project engineers". In turn, the "group leader" is given the responsibility of providing the leadership and guidance to coordinate the group work to meet project deadlines.

The F-W Module prepared by MEL has been used as the framework for the project, but has been extended to include a pollution prevention component, consisting of identification of "bad actors", development of a revised process flowsheet with the incorporation of new waste minimization technologies, and a cost analysis for process revisions and potential savings from process modifications and waste minimization. Two additional MEL developed modules are also available to students for this portion of the assignment: Wastewater Treatment Plant and

Visual Encyclopedia of Chemical Engineering Equipmentt. With the addition of the pollution prevention component, students are exposed to an "open-ended" design problem similar to that which they might traditionally encounter in a senior level design class.

The various tasks in the project vary from presentation of a process flowsheet, detailed material balance calculations, a revised process flowsheet including waste minimization strategies, and description of new waste treatment technologies by the project engineers. Each task completion involves a group Memo Report and an oral presentation either to the "project director" or the entire class. At the completion of the project, each "project engineer" submits individual Peer and Group Leader Evaluations, and the "group leader" submits an Jr. Engineer Evaluation (similar to a merit review) to the "project director". All these are considered in assigning the final grades.

The results of three years of testing this approach will be presented. A home page for the Material Balances class (ChE 211) has been developed which contains the various aspects of the class and the F-W project (URL: http://www.che.orst.edu/211/che211.htm)

INTRODUCTION

The description of the use of the Ford-Wixom module as a project in a traditional Chemical Engineering Material Balances class will be given using a series of handouts that are presented to the students. The most current versions of the University of Michigan Multimedia Education Laboratory (MEL) modules were obtained in CD-ROM format (Susan Montgomery, Department of Chemical Engineering, University of Michigan, smontgom@engin.imich.edu) and downloaded to the OSU ChE Department computer server for general student access.

Material Balances is a 4 credit course offered over a 10 week quarter. The equivalent of 1 cr. (2 hours per week) is allocated to the F-W project and the project covers approximately 8 weeks of the quarter, with 2-3 weeks for final group presentations. There are typically 50 - 60 students in the course (85% ChE, 10% EnvEng, 5% Biological Eng.), which usually means about 15 student groups. Each group is assigned a "group leader" -- a Jr. or Sr. ChE student who has already gone through the F-W module. These "group leaders" are enrolled in a 1 cr. Leadership and Mentoring course (see paper 2213-03) and are involved with both the functioning and guidance of the groups, as well as evaluation of student work as the various "tasks" are completed and submitted for approval. I would venture to say that the management of the F-W project would be virtually impossible without these 15 group leaders (or equivalent TA support) to help with student questions and day-to-day troubleshooting.

FORD-WIXOM PROJECT

In addition to the F-W module itself, the students are presented with the following information concerning the F-W project:

1) Problem Statement (Table 1)
2) Background Information (Table 2)
3) Tasks and Timelines (Table 3)
4) Final Task and Timeline (Table 4)

This information, in the form of handouts, is presented in the various Tables given at the end of the paper.

EVALUATION
How effective is this "open ended problem" approach and how is this additional "workload" received by the students ? To help determine the effectiveness of this type of activity, performance evaluations across all levels are conducted. Students evaluate both mentors and their peer group members, while mentors evaluate the students in their respective groups. Both the students and the mentors are asked to evaluate the F-W module itself and the group activity aspect of the project. All of these evaluations are used by the instructor in the final performance evaluations of the mentors and the grading of the students for their project work. All evaluations are maintained confidential by the instructor to encourage honest and direct assessments by students and mentors. This method of evaluation has proved effective in minimizing "problem groups" or "problem mentors", particularly when all parties are told at the outset exactly what the evaluation criteria will be and how they will be used.

In the ChE 211 Material Balances course, the mentor primarily serves as the Project (Group) Leader and is asked to give a "performance review" for each project engineer and for the group as a whole (Table 5), much like an engineering manager might be asked to do in industry. The project engineers are given the opportunity to give "performance reviews" of both their fellow project engineers (peer group) and to their group leader (Table 6).

CONCLUSION
The F-W module as a quarter long project has been used for the past three years in the Material Balances course. While some students complain about the additional workload, the majority enjoy working on a "real-life" project in groups and getting to know their classmates better on a different level. Many students have commented that the exposure they received to mass balances and pollution prevention technologies in the F-W project have been useful in subsequent engineering internships. There is a DOE funded Industrial Assessment Center (IAC) at OSU which conducts wastes and energy audits for small companies. In the past three years, 20 -25 ChE students have had internships in the IAC, whereas in the previous three years no more than 3-4 ChE's had received positions. This is an almost direct result of the "practical experience" they receive in doing the F-W project, which provides them with the basic tools and background to perform effectively in the IAC.

The undergraduate students really enjoy having contact with older students and truly do view them and use them as resources. This is evidenced by the fact that we more frequently here comments like "...my junior mentor told me that..... I can take Health S/U, GEO 300 is any "easy" Bacc core class, don't take Heat Transfer with Professor so and so, taught me how to graph in Excel and use PowerPoint for presentations, ...etc.". The older students (Jr. and Sr.) seem to really enjoy being able to help the younger students with their problems. It boosts their self-esteem and helps them to realize that they REALLY are learning something from their time in school, and that they have made progress from their early years. In all cases, the "big brother/sister" concept provides a healthy sense of community within the chemical engineering department, which didn't exist three short years ago.

BIOGRAPHICAL INFORMATION
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Research interests in polymer materials characterization and processing, and undergraduate engineering education.

Table 1: Ford-Wixom Problem Statement

ChE 211 Mass Balances and Chemical Engineering Process Calculations
FORD-WIXOM MODULE

Phosphate Conversion Coating Prior to Painting of a Car Body
The introduction section of the F-W Module gives you the problem statement. There is a picture of a guy sitting there, but the computers don't have audio cards, so you need to access the Text of the Problem Statement using one of the screen buttons.

The problem statement is very open-ended - basically minimize the waste streams.

I would add that you should consider minimization of both environmental impact and costs. If you draw a large box around the entire process, anything that crosses that boundary can be assigned an economic value. For instance, the car bodies leave the plant which provides a "positive" cash flow. Any raw materials (water and chemicals) that enter or leave involve a cost. Any waste stream that leaves the plant involves a cost. Any time you can reduce the amount of raw materials entering or wastes leaving the plant, you generate profit. This is the essence of chemical engineering process design for resource reuse and waste minimization. This is much different than end-of-the-pipe waste treatment or waste remediation of toxic sites.

The F-W Module project should be broken down into a series of tasks, which are outlined below:
Task #1: Develop a preliminary flowsheet of the Phospahte Conversion Coating Process (PCCP)
Task #2: Mass Balances on the Process Stages
Task #3: Overall Mass Balance for the PCCP
Task #4: Identify methods for resource reuse and waste minimization
Task #5: Proposed Waste Minimization Strategy -- Costs and Savings
Task #6: Revised Process Flowsheet and Mass Balance for the PCCP
Task #7: Pollution Prevention Technologies

Table 2: Ford-Wixom Project -- Background Information

In building quality products that require painting, excellent appearance and corrosion resistance are extremely important customer expectations. Paint, however, does not readily adhere to pure metal surfaces such as cold rolled steel or aluminum. Before metal can be painted, a surface coating (also known as a conversion coating) must be applied that will retard base metal corrosion and allow the paint to firmly adhere to the metal. A chemical conversion coating process, typically using a phosphate material, is typically applied to the metal prior to painting. This conversion coating process can be defined as a process which transforms metallic surfaces to non-metallic or semi-metallic crystalline surfaces. Once the metal undergoes the phosphate coating, the resulting inorganic crystalline coated surface provides an excellent base for paint.

The purpose of the phosphate coating as a base for paint is to:

¥ Improve paint adhesion
¥ Reduce metal to paint reactions.
¥ Improve corrosion resistance.

Phosphate coatings are used to prepare most painted metal objects (not only car bodies) produced by industries today because of the increased durability of the final product. The typical high quality pre-paint conversion coating process consists of the following basic steps:

¥ Metal surface cleaning.
¥ Rinsing

- ¥ Phosphate coating application.
- ¥ Rinsing
- ¥ Post-Phosphate treatment
- ¥ Deionized water rinse

There are many variations of this basic process throughout the industry, based upon the product quality performance criteria (car body vs. filing cabinet vs. landing gear on a Boeing 757) and the base metal being coated (e.g., steel vs. aluminum).

During the summer of 1993, a study of the phosphate conversion coating system at the Ford Motor Company's Wixom Assembly Plant (Michigan), which was installed in 1989, was performed. The following is an overview of this process, the details of which are covered in the Ford-Wixom Module prepared by the University of Michigan Multimedia Education Laboratory (MEL) from a detailed analysis of this process.

Overview: Ford-Wixom Phosphate Conversion Coating Process

Vehicle parts (bodies or panels) enter the phosphate coating system after being stamped into their respective shapes and sometimes welded together. Many oils and other compounds are used in this process, and the parts can also become contaminated with dirt and weld residue. The part surface must be thoroughly cleaned to allow high quality conversion coating of the phosphate material to occur. To remove the bulk of these contaminants, the parts are passed through a high pressure spray "pre-wash" system.

Although the pre-wash removes some of the dirt and contaminants, since it is very important to have an absolutely clean surface for coating, the first two stages of the process are also cleaning stages. Stage 1 is a high pressure spray cleaner, and Stage 2 is an immersion tank cleaning. The immersion application alleviates any concerns related to part complexity (dirt in hard to reach areas) and insures the part has been cleaned inside and outside.

Once cleaned, the parts must be thoroughly rinsed. The major function of the water rinse stages is to remove any cleaning chemicals and prevent contamination of subsequent baths. Stages 3 and 4 are both water spray rinses.

After the parts have been cleaned and rinsed, the surface needs to be prepared to accept the zinc phosphate treatment. The surface chemistry takes place in an immersion rinse conditioning stage (Stage 5), where a surface activating agent reacts with the metal surface to create nucleation sites for the growth of the coating crystals.

After the surface has been properly prepared, it is ready for the conversion coating solution. Most conversion coatings used by the metal finishing industry are based on mixtures of partially neutralized phosphate acid. Stage 6 is an immersion phosphate coating bath. This is the major stage in the process in that most of the important chemistry occurs at this point. A necessary by-product of this process is the formation of a sludge produced by the iron which is dissolved and then oxidized in solution to form an insoluble mixture of ferric phosphate and ferrous phosphate. The sludge from Stage 6 is collected and dewatered in a filter press.

Once the parts leave the Stage 6 phosphating bath, they must be rinsed to remove the unreacted chemicals from the surface in order to prevent contamination of the next stage. Stage 7 is a spray rinse and Stage 8 is an immersion rinse.

After the metal surface receives a conversion coating and has been sufficiently rinsed, a post-treatment is applied. The function of this post-treatment is to provide an increase in corrosion and humidity resistance (approx. 2 - 10 times increase in effectiveness). Post-treatment has historically been based on chromic acid, although non-chromate chemicals are used throughout the industry. Stage 9 is an immersion chrome/water rinse.

One disadvantage of chromic acid is that high concentrations can form in corners and seams which could lead to poor corrosion resistance in these areas. For this reason, excess chrome is rinsed off in a series of deionized water (DIW) rinse stages. Stage 10 is a recirculating DIW spray rinse, Stage 11 is a recirculating DIW immersion rinse, and at the end of stage 11 is a VIRGIN DIW (new DIW) water spray whose runoff flows directly into stage 11.

Now the parts (vehicle bodies and panels) are ready to be painted!

TABLE 3: TASKS AND TIMELINES

Task #1: Develop a flowsheet of the Phosphate Conversion Coating Process
¥ INDIVIDUAL Project (each group member must submit a draft flowsheet)
¥ the "first draft" flowsheet should contain all the basic process steps (spray rinse, immersion rinse, etc.) with all the streams entering and leaving each stage (including recycle streams, tank dumps, wastewater treatment streams (WWT), chemical additions, water additions, and "carryover").
¥ the "first draft" flowsheet should NOT include stream flows and mass balance calculations.

Task #2: Mass Balance on the Process Stages
¥ Choose a Basis for calculation (based on available data for dumps, etc.).
¥ Divide the process into convenient "subunits" for calculation purposes (HINT: Stages which are connected through "recycle loops" are useful subunits).
¥ Develop an understanding of the chemistry and operating conditions of each stage.
¥ Determine the Mass Balance for each stage (or subunit if appropriate).

Task #3: Overall Mass Balance for the Phosphate Conversion Coating Process
¥ Combine the individual stage and subunit mass balances for an overall mass balance.
¥ Prepare a TABLE of RESULTS for the mass balances on each stage or subunit group.
¥ Prepare a final flowsheet of the process as it exits.

Task #4: Identify "bad actors" for waste and waste minimization strategies
¥ identify MAJOR "bad actors" for waste.
¥ waste minimization strategies: recycle and reuse; dump schedule changes: etc.

PROBLEM STATEMENT: POLLUTION PREVENTION for COST SAVINGS
Any stream that leaves the plant cost $$. The goal is to minimize the material leaving the plant.

Task #5: Proposed Waste Minimization Strategy -- Costs and Savings
¥ process innovations which allow for resource recovery (e.g., membrane R-O systems, etc.)
¥ process modifications: consolidation of stages; filter units; soft water for DIW; etc.
¥ process changes: chemistry -- is there an alternative to the Chromium Rinse?; soft water
¥ estimates of resource savings from the proposed waste minimization strategies.
¥ NOTE: A detailed economic analysis is NOT NECESSARY.
Make some "engineering guesstimates" of costs (e.g., X gallons of water saved at $/gal).
¥ COST BASIS: F-W Plant located in Corvallis, OR

Task #6: Revised Process Flowsheet and Mass Balance for the Phosphate Conversion Coating Process
¥ flowsheet and mass balance should reflect your proposed changes (you may just highlight those stages in the flowsheet which are different than the original process flowsheet.).
¥ TABLE of savings (wastes reduction) and costs (new technologies or resources).

Task #7: Waste Treatment Technologies
¥ evaluate the various technologies available for treatment of the waste streams generated by the process (in particular the sludge streams).

F-W Project TIMELINE
Task #1: THURSDAY, JANUARY 15, 1998
Tasks #2, #3, #4: WEDNESDAY, FEBRUARY 11th, 1998
Tasks #5, #6, #7: Final Presentations, Wednesday, March 12, 1998

TABLE 4: FINAL TASK: POLLUTION PREVENTION FOR COST SAVINGS

(Combined Tasks #5, #6, #7)
Summary of Expectations:
1) Identify ALL potential "bad actors" -- even if you don't act on them.
¥ examine INPUTS/OUTPUTS for the F-W plant to see if resources or wastes can be minimized.

2) Identify "appropriate" waste minimization strategies
¥ select the areas of major focus -- greatest potential for costs savings.
¥ briefly explain those "bad actors" that will be ignored.

3) Identify "appropriate" technologies for waste minimization.
¥ which technologies will work and what will be the cost (approximate).

4) Revised process flowsheet -- improvements highlighted.
¥ note on flowsheet which technologies will be used for which application.

5) Final Recommendations
¥ Summary table of technologies implemented and in which area of the plant.
¥ TABLE of costs and cost savings (use COST DATA provided by Dr. Rochefort).

FINAL REPORT: F-W PROJECT DELIVERABLES (due Thurs., Feb. 19, 1998)

1) Cover Page -- MEMO Format (signed by ALL members -- including group leader)
¥ summary of all "bad actors" -- those acted upon and ignored
¥ summary of final recommendations to rectify "bad actors" (including technologies implemented)
¥ summary of costs and costs savings

2) PROCESS FLOWSHEET -- as determined from F-W Module

3) MASS BALANCE TABLE -- summary of mass balance calculations (tasks #2, #3, #4)

4) REVISED PROCESS FLOWSHEET -- pollution prevention modifications highlighted.

5) TABLE of WASTES REDUCTION and COST SAVINGS

6) Summary TABLE of TECHNOLOGIES implemented

7) Bibliography
¥ include all references used -- even personal communications.

8) Appendix: Detailed Calculations and Cost Analysis
¥ include all assumptions and BASIS for all calculations.
¥ Stage-by-stage mass balance and cost calculations

INDIVIDUAL Jr. Engineer PROJECT (assigned by Group Leader)
Evaluation of a Pollution Prevention Technology
¥ 1 page written explanation of a pollution prevention technology (either used or evaluated for use)
¥ schematic illustration of the technology to aid with explanation.

TABLE 5. Ford-Wixom Jr. Engineer and Project Evaluation (Winter 1997)

NOTE: This will be reviewed only by Dr. Rochefort. Please be thorough - it is important.

Group Leader: ________________________________ DATE: __________________
Junior Engineer Evaluation: (Give rating of 1 (poor) to 5 (very good) in each category).

Name : ____
Availability (around when needed; meeting attendance):
Communication Skills (written and oral):
Participation/Enthusiasm (where they active group member):
Task Performance ("On time" delivery of assignments):
Technical Skills (basic engineering skills; neat, clear, organized work)
OVERALL Performance (would you want this person in your group):
Comments:

SUMMARY EVALUATION:
Strengths:
Weaknesses:

Name : ____
Availability (around when needed; meeting attendance):
Communication Skills (written and oral):
Participation/Enthusiasm (where they active group member):
Task Performance ("On time" delivery of assignments):
Technical Skills (basic engineering skills; neat, clear, organized work)
OVERALL Performance (would you want this person in your group):
Comments:

SUMMARY EVALUATION:
Strengths:
Weaknesses:

Name : ____
Availability (around when needed; meeting attendance):
Communication Skills (written and oral):
Participation/Enthusiasm (where they active group member):
Task Performance ("On time" delivery of assignments):
Technical Skills (basic engineering skills; neat, clear, organized work)
OVERALL Performance (would you want this person in your group):
Comments:

SUMMARY EVALUATION:
Strengths:
Weaknesses:

NOTE: You have been given a $10,000 BONUS to distribute based on merit to the Junior Engineers in your group. Indicate the BONUS AMOUNT for each engineer.

F-W Project Evaluation: Comment on the F-W module itself and the concept of a group project with sophomore students as junior engineers. Was it a worthwhile learning experience? Why or why not ? PLEASE BE AS SPECIFIC AS YOU CAN -- it will help those who follow in your footsteps!
Use back side of sheet if necessary.

TABLE 6: Ford-Wixom Group Leader, Peer and Project Evaluation

NOTE: This will be reviewed only by Dr. Rochefort. Please be thorough - it is important.

Name: ____ DATE: ________________

Group Leader Evaluation: (Give rating of 1 (poor) to 5 (very good) in each category).
GROUP LEADER (s):____
(NOTE: If two group leaders, please evaluate each separately)
Availability (around when needed?):
Communication (did they inform group of meetings, activities, etc.):
Scheduling (adequate meeting times and proper advance notice):
Technical Skills (basic engineering skills -- does NOT imply knowing all the answers):
Organization (task assignments and workload distribution):
Leadership/Guidance (did they act like the "boss"?):
OVERALL Performance (would you like to work for this person?):

COMMENTS (strengths and weaknesses):

Peer Evaluation of Group Performance:
This is the opportunity for each member of the group to rate the performance of their group colleagues in the completion of the Ford-Wixom Project. The peer evaluation process is commonly used in industry to evaluate group dynamics and group performance characteristics. It provides each group member with the opportunity (and responsibility) to provide feedback to management on the effectiveness of a working group.
The system that we have adopted for use in ChE 211 is the merit raise system. Each group is given $10,000 as a year-end bonus for a job well done, and each group member is given the opportunity to distribute this bonus money as they desire, based on how they view the contributions of each member to the overall performance of the group and success of the project.
Examples:
1) Group ABCD member A feels that everyone in the group contributed equally to the successful completion of the project within given deadlines, they would give $2500 to each member.
2) Group ABCD member A feels that they did most of the work and that D did not contribute, then the distribution might be $5000 for A , $2500 each to B and C and $0 for D.

Name (group member): _____________________________________ bonus $ ____________
Name (group member): _____________________________________ bonus $ ____________
Name (group member): _____________________________________ bonus $ ____________
Name (group member): _____________________________________ bonus $ ____________

Evaluation of overall Group Performance:
How well did you do at completing your PROJECT? very good good fair poor
COMMENTS:

F-W Project Evaluation: Comments on the F-W module itself and the concept of a group project with ChE students as group leaders. Was it a worthwhile learning experience? Why or why not ? PLEASE BE AS SPECIFIC AS YOU CAN -- it will help those who follow in your footsteps!
Use back of sheet for your comments if necessary.