PROCESS DESIGN PROJECT
ECH 4604

This is *not* the big one —
but it is the warm-up for the big one!

Background

Throughout our Chemical Engineering curriculum, students have tackled assignments of successively greater scope and complexity. This educational plan continues in Process Design I.

This semester, students gain experience in tying together the concepts and skills from their prior coursework by taking on a project in process design. This project is based on a process involving *both* chemical reaction *and* chemical separation, as well as utilizing principles from thermodynamics, fluid flow, heat transfer, and other areas.

The project also enables students to apply material gained this semester in Process Design I. Thus, the project will involve the use of process flow diagrams, process computer software (CHEMCAD), and process economics.

It is essential that each student work intensively on this assignment. In this way, students will be well prepared for probably their greatest challenge of their undergraduate engineering education – their major design project – which will be presented in the Process Design II course.

ABET Criterion 4

The Accreditation Board for Engineering and Technology (ABET) establishes criteria for accrediting engineering programs in the United States. Students have been introduced to Criterion 3 in prior courses.[1]

We now call attention to a section of ABET Criterion 4:

> Students must be prepared for engineering practice through the curriculum culminating in a major design experience based on the knowledge and skills acquired in earlier course work and incorporating engineering standards and realistic constraints that include most of the following considerations: economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political.

Thus, as you speak with engineering students in other disciplines such as Electrical, Civil, Mechanical, or Industrial Engineering, you will find that they are challenged by major design projects of broad scope and complexity. Similarly, as you speak with chemical engineering students from other universities, you will find that they too are undertaking design projects comparable to those at the FAMU-FSU College of Engineering. Finally, as you speak with chemical engineers who have practiced for five, ten, twenty, or thirty years, you will find that they took on a major design project while in school and that, moreover, it was one of the most satisfying experiences of their undergraduate education.

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[1] Refer to the Laboratory Manual for ECH 3274L and ECH 4404L.

Learning Objectives

By the end of this assignment, the student will be able to:

- Apply chemical reaction, chemical separation, and other chemical engineering principles to design a chemical process involving multiple unit operations.
  (*Outcome A, C,* Level 4) (*Outcome B, E, F,* Level 3)
- Optimize a new process design, in terms of project investment, by adjusting reaction temperature.
  (*Outcome A, C,* Level 4) (*Outcome B, E, F,* Level 3)
- Use CHEMCAD in other applications. (*Outcome K,* Level 3)
- Write, as a team member, a technical report that evaluates the design and profitability of a new process.
  (*Outcome C, G,* Level 6) (*Outcome F,* Level 3)
- Contribute as a team member on a process design project. (*Outcome D, F, G,* Level 3)

Assignment Format

This assignment will be completed by each student team, as determined in the first week of this course.

Student teams will complete the design project independently. Students are not allowed to discuss any aspect of the design project with anyone outside their team.

Other than the conference with the instructor on the interim report (see below), the instructor will not provide any guidance or feedback to students.

Any questions, suggestions, concerns, or complaints must be submitted to the instructor by e-mail. No student comments or discussion of the design project will be allowed during the class period. Nor will the instructor receive any student questions or comments on the design project in the hallway, in the atrium, or in any other informal setting. Students failing to comply with these rules will be subject to penalties on the course grade.

In rare instances, the instructor may request to meet with students in the instructor's office to discuss issues raised by students in prior e-mail messages.

Students are encouraged to utilize textbooks, handbooks, encyclopedia, journals, vendor literature, and Internet resources.

Students are expected to uphold the Academic Honor Code of FAMU and FSU. Team members of one team may not provide information on the design project to another team. Any team violating the Academic Honor Code will be subject to penalties and could get a failing grade for the course.

Project Announcement
The specific design project for this assignment will be announced in class on October 22, 2003.

For this year, the design project will be TBWS[2], Appendix C, Project 6: "Design of a New, 100,000 Metric Tons per Year Cumene Production Facility"[3]. Appendix C may be found on the CD accompanying the textbook. Students who have misplaced the CD may contact the instructor by e-mail for a copy of the project description. For convenience, a copy of the design project is attached.

> *Note: Read the project description carefully, thoroughly, and frequently. Make sure you understand what process data are specified and what deliverables are required.*

Interim Report
Students will prepare an interim report. This report will focus on setting up and solving the basic engineering equations describing the process for some example process conditions. Thus, this phase of the project work applies the framework and methodologies for process design that were reviewed in lectures, homework, and quizzes during the first part of the Process Design I course. (Although process economics will not be considered in the interim report, it will be a central element of the final report.)

The interim report will be graded, contributing a maximum of 8 points to the overall course grade. Students who do not submit an interim report will receive a "0".

The interim report will provide the following:

a. A Process Block Diagram. The diagram must be consistent with the guidelines presented in the TBWS textbook.

b. A skeleton Process Flow Diagram. The diagram must be consistent with the guidelines presented in the TBWS textbook.

c. Appropriate equations for the mass and energy balances for each unit operation. These equations may be presented in a form consistent with the Case Study Lecture on October 1, 2003.

d. The solution of the above equations by hand (or spreadsheet). Assume that the fractional conversion of the base reactant is 0.52 to form product and 0.04 to form by-product. If the reactions involve more than one reactant, base the fractional conversion on the raw material with the highest molecular weight. Also, assume that the molar ratio of reactants entering the reactor is 1.5, so as to reduce formation of by-product.

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[2] Turton, R., Baillie, R.C., Whiting, W.B., and Shaeiwitz, "Analysis, Synthesis, and Design of Chemical Processes", 2nd Ed., Prentice Hall PTR, Upper Saddle River, NJ, 2003. [ISBN 0-13-064792-6]
[3] Students may find information, which is useful for Project 6, in a related exercise in TBWS, Appendix C, Project 5, "Problems at the Cumene Production Facility, Unit 800".

Develop a Flow Summary Table for this case. The table must be consistent with the format presented in the TBWS textbook (e.g., Table 1.5).

e. The conversion of the reaction at 300 °C based upon a reactor volume 10 m^3. The solution should be by hand (or spreadsheet).

   Develop a Flow Summary Table for this case. The table must be consistent with the format presented in the TBWS textbook.

Students may want to use CHEMCAD to supplement and cross check the calculations above. Please note that the CHEMCAD solution is required in the final report, but is not required for the interim report.

Note: The above process assumptions and conditions are provided for the interim report only. For the final report, students are expected to optimize the process conditions.

Interim Conference

Teams will meet with the instructor to gain feedback on the interim report on Monday, November 17, in the instructor's office at the following times:

Team No.	Time		Team No.	Time		Team No.	Time
1	1:00		2	1:15		3	1:30
4	2:00		5	2:15		6	2:30
7	3:00		8	3:15		9	3:30
10	4:00		11	4:15		12	4:30
13	5:00		14	5:15		15	5:30

The Process Design instructor has arranged with the Unit Operations Lab instructor, who has graciously agreed to make the time slot from 1:00 pm to 5:00 pm available. Accordingly, it is expected that most students will be able to make the above appointment times. Teams who have conflicts with the above times should notify the instructor by e-mail before Friday, November 14, to schedule an alternate conference time.

Final Report
The final report will build upon the basic solution of the engineering equations developed for the interim report. Students will be expected to set up the entire process on CHEMCAD and then use CHEMCAD to solve various process equations. Students are encouraged to review their CHEMCAD lectures and assignments from the first part of the Process Design I course.

The final report will also emphasize process economics. Cost of equipment, manufacturing cost, and profitability will be considered. These topics are well covered in TBWS, Chapters 5 to 8. Highlights from these chapters will be presented during the latter part of the Process Design I course.

Applying CHEMCAD skills and process economics know-how, students will optimize the process, in terms of the project investment, by adjusting the reactor temperature. The final report will consider at least five reactor temperatures over the range 300 °C to 400 °C. Another factor to consider is the mole ratio of reactants fed to the reactor.

Specifics items to be addressed in the final report are detailed in the project description. In addition, the report should present a table summarizing key results from the reactor temperature optimization.

As this is a preliminary design, we shall make some additional assumptions that may prove helpful in the economic evaluation:

- The raw material market costs presented in TBWS Table 6.4 are valid.
- The utility costs presented in TBWS Table 6.3 are valid.
- The catalyst cost is negligible.
- The by-product is waste that has only fuel value.

All students are strongly encouraged to back up their reports on floppy disks or other media frequently during their work sessions at the computer. Check the backup disk to make sure that it indeed is functioning properly as a backup. Students are also advised to maintain various sections of the report in different computer files, in order to reduce the chance of losing an entire report.

The instructor will not accept "lost computer files" as an excuse for late reports.

Due Date and Time

Interim Report: Friday, November 14, 2003 at 11:00 am.

Final Report: Friday, December 5, 2003 at 11:00 am.

Students facing hospitalization, death in family, or other extraordinary situations must promptly inform the instructor in order to be considered for an excused extension beyond the assignment due date.

Without an approved excuse, no report will be accepted after the due date and time listed above.

Submit the report to the secretary or clerk in the Chemical Engineering Office, who will stamp the report with the date and time, and place it in the instructor's mail box.

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PROJECT

6

Design of a New, 100,000 Metric Tons per Year Cumene Production Facility

BACKGROUND

In the opinion of our marketing research department, the demand for phenol-derived plasticizers is on the rise. Therefore, we are investigating the possibility of a new, grass roots phenol plant to handle the anticipated increase. Because phenol is made from cumene, a grass roots cumene plant would also be necessary. Given your experience in trouble-shooting our existing cumene process, we would like you to study the economics of a new cumene plant. Specifically, we would like a complete, preliminary design of a grass roots, 100,000 metric ton/yr cumene process using benzene and propylene.

We have a new, proprietary catalyst, and the kinetics are included in Table C.17. We would also like you to consider the economics of us continuing to use propylene with 5% propane impurity at $0.095/lb versus purer propylene feed. In preparing this preliminary design, you should assume that all steam made can be used elsewhere in the plant with the appropriate economic credit, that condensed steam can be returned as boiler feed water for the appropriate credit, and that fuel gas can be burned for credit at its LHV (lower heating value). Additional information is given in Table C.18.

ASSIGNMENT

Your assignment is to provide:

1. An optimized preliminary design of a plant to make cumene from benzene and propylene using the new catalyst.

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2nd Ed., Prentice Hall PTR, Upper Saddle River, NJ, 2003. [ISBN 0-13-064792-6]

Table C.17 Reaction Kinetics for Cumene Reactions (Unit 800)

The kinetics for the reactions are as follows:

$$\underset{propylene}{C_3H_6} + \underset{benzene}{C_6H_6} \xrightarrow{k_1} \underset{cumene}{C_9H_{12}}$$

$$r_1 = k_1 c_p c_b \quad \text{mole/g cat sec}$$

$$k_1 = 3.5 \times 10^4 \exp\left(\frac{-24.90}{RT}\right)$$

$$\underset{propylene}{C_3H_6} + \underset{cumene}{C_9H_{12}} \xrightarrow{k_2} \underset{p\text{-diisopropyl benzene}}{C_{12}H_{18}}$$

$$r_2 = k_2 c_p c_c \quad \text{mole/g cat sec}$$

$$k_2 = 2.9 \times 10^6 \exp\left(\frac{-35.08}{RT}\right)$$

where the units of the activation energy are kcal/mol, the units of concentration are mol/l, and the temperature is in Kelvin.

For a shell-and-tube packed bed, the recommended configuration, the following data may be assumed:

- catalyst particle diameter d_p = 3 mm
- catalyst particle density ρ_{cat} = 1600 kg/m^3
- void fraction ε = 0.50
- heat transfer coefficient from packed bed to tube wall h = 60 W/m^2°C
- use standard tube sheet layouts as for a heat exchanger
- if tube diameter is larger than in tube sheet layouts, assume that tube cross sectional area is 1/3 of shell cross sectional area

2. An economic evaluation of your optimized process, using the following information:
   - After-tax internal hurdle rate = 9% p.a.
   - Depreciation = MACRS (6 year schedule see Chapter 7)
   - Marginal taxation rate = 35%
   - Construction period = 2 years
   - Project plant life = 10 years after start-up

Specifically, you are to prepare the following by . . . (4 weeks from now)

1. A written report detailing your design and profitability evaluation of the new process.

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Table C.18 Additional Information (Unit 800)

Cost of Manufacture

In order to estimate the cost of manufacture (not including depreciation), COM_d, you should use the following equation:

$$COM_d = 0.180\ FCI + 2.73\ C_{OL} + 1.23\ (C_{UT} + C_{WT} + C_{RM}) \qquad (3.2)$$

The current MACRS method for depreciation should be used in your calculations (see Chapter 7.

Hints for Process Simulator

The CHEMCAD™ process simulator was used to generate the flow table given in Project 5. The hints given here are specifically directed to CHEMCAD™ users but should also be applicable for other process simulators.

Use SRK (Soave-Redlich-Kwong) thermodynamics package for VLE and enthalpy calculations for all the equipment in the process.

For heat exchangers with multiple zones, it is recommended that you simulate each zone with a separate heat exchanger. Actual equipment may include several zones, so costing should be based on the actual equipment specifications.

For the reactor, you may use an isothermal reactor to estimate the volume of catalyst and heat exchange area. For more accurate results the temperature profile in the reactor should be modeled by completing a differential heat and material balance on the reactor.

For the distillation columns, you should use the shortcut method (SHOR) to get estimates for the rigorous distillation simulation (TOWR or SCDS). The shortcut method may be used until an optimum case is near. It is then expected that everyone will obtain a final design using rigorous simulation of the columns.

When simulating a process using "fake" streams and equipment, it is absolutely necessary that the process flow-diagram you present not include any "fake" streams and equipment. It must represent the actual process.

2. A clear, complete, labeled process flow diagram of your optimized process including all equipment and the location of all major control loops.
3. A clear stream flow table including *T*, *P*, total flowrate in kg/hr and kmol/hr, component flowrate in kmol/hr, and phase for each process stream.
4. A list of new equipment to be purchased, including size, cost, and materials of construction.
5. An evaluation of the annual operating cost for the plant.
6. An analysis of the after-tax NPV (10 years, 9%), and the discounted cash flow rate of return on investment (DCFROR) for your recommended process.

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7. A legible, organized set of calculations justifying your recommendations, including any assumptions made.

REPORT FORMAT

This report should be in the "standard" design report format, consistent with the guidelines given in Chapter 26 of this text. It should include an abstract, results, discussion, conclusions, recommendations, and an appendix with calculations.