A COURSE MODULE ON CHEMICAL PRODUCT DESIGN

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The changing nature of the chemical engineering profession has promoted interest over the past decade in introducing students to product design concepts in addition to traditional chemical process design. The author began teaching design at Louisville in fall 2004 following the retirement of a senior colleague who had taught it for many years, and decided to incorporate a module on product design into the second course of a two-course sequence. The students survey the text “Chemical Product Design” by Cussler and Moggridge (2001) and then are required to spend about one month identifying a needed product and performing a preliminary product design for it, including financial analysis, following the Cussler-Moggridge procedure.

Some products proposed and analyzed over the past four years include:

- A swizzle-stick capable of detecting a date-rape drug in a mixed drink
- Chewing gum to whiten teeth
- Nanofluid production using induction heating, and
- Design and production of a better golfball.

The paper discusses these student projects, as well as some common issues students have with such an open-ended exercise. Student projects are generally of acceptable quality and show that graduates can think and rise to a challenge, even as they are about to be loosed on an unsuspecting world!

INTRODUCTION

Chemical Engineering Design at University of Louisville consists of a two course sequence offered in the 4th year of the program. The present author began teaching the design sequence in 2004. CHE 471, Strategy of Design, is a basic “how to do design” course, comprising flow-sheet development, component design, use of process simulators (Aspenplus) and process economics including profitability analysis. Over the course of the semester each student develop a design process to synthesize his or her own assigned commodity chemical. The second course, CHE 572, Plant, Process, and Project Design, focuses on teamwork. In the first eight weeks of the semester (from start of semester to Spring Break) students prepare a team design report with a topical focus, for example biodiesel synthesis, or the AIChE design contest problem. For the four to five week period between Spring Break and the end of semester, a module on Chemical Product Design was introduced, and is the focus of the remainder of this paper.

Chemical Product Design

Several authors of the past decade have proposed that today’s Chemical Engineering design courses need to include some instruction on Chemical Product Design (see for example: Moggridge and Cussler 2000, 2003; Westerberg, 2000; Shaeiwitz and Turton, 2001; Grossmann, 2003; Wei, 2004; Cussler, 2006; Moggridge et al, 2008). This has been reinforced by the changing nature of the chemical industry in the US. Large scale new production of commodity chemicals is being off-shored while the domestic focus is often on specialty chemicals and new products. 2001 saw the publication of the monograph "Chemical Product Design" by Cussler and Moggridge which presented an easy avenue to introduce the topic into a design course.

The Cussler-Moggridge text is easily surveyed in a half dozen classroom lectures and presents a solid framework for students to develop a product design study. Topics presented in the text and in class include:

- Why students ought to be interested in product design
- Assessment of customer needs
  - Market analysis
- Generation of ideas to meet the needs, through brainstorming sessions
- Culling and selection of ideas for further study
  - Patents and trade secrets (Presentation by an alumna who is a patent attorney)
- Product manufacture and how it compares to traditional process design
- Economic issues, again compared to process design

The text material is interspersed with a wealth of examples of successful products, ideas for new products and "quick and dirty" analysis approaches appropriate to rapid selection of workable ideas for further study.

Class Mechanics

The 4th year class at Louisville in recent years has ranged in size from 15 to 30 students; class sizes projected for the next several years are closer to 30 students per year. Students are given considerable latitude in how they approach the product design project. They may work individually, in teams of 3 or 4, or even as a whole class, though no group has even taken this option. This project comes in what may be the last month of formal education for many of the students and often "senioritis" is rampant among even the more dedicated members of the class. The product design assignment is presented to them as a project that ought to be undertaken as a challenge to be creative and, within, some reasonable bounds, should be viewed as a "fun" exercise. This is their opportunity to be innovative and inventive, and obviously the effort they put into the exercise will reflect what they get out of it. This approach seems to work with most students and leads to their putting an appropriate level of effort into the project.

Figure 1 shows the problem statement as presented in spring semester 2008. Figure 2 shows the outline format provided for the final report; some leeway is allowed here as the exact product chosen will often dictate how specific some areas of the report can get. Generally the textbook material occupies the three weeks or so before spring break, while the class is working on that semester's first project which is due at last class before break. The assignment for the product design project is distributed at one of the classes in the week before spring break with the instructions that they decide know how they will work on the project (individually, in teams with members specified, etc.) by the class immediately following the break.

Selected Projects from Past Three Years

Given the constraints on how the course is organized the quality of the final projects has varied somewhat each year. However the vast majority of the students have taken the product design project quite seriously and produced creditable work. Table 1 lists the products designed by these four student groups. While some of the ideas may be somewhat far-fetched, and a few others show insufficient research to see that they copied existing products or patents, there were surprising few completely sophomoric proposals. Alcohol-related concepts often featured in the initial product list generated by brainstorming ("boys will be boys!") but relatively few of these made it to final selection. Many of the ideas came from the students' own life experiences by asking "Wouldn't it be nice if … ". Brief discussion of some of the more interesting ideas follows the table.

TABLE 1: SUMMARY OF PRODUCTS DESIGNED BY STUDENTS IN CHE 572, 2005-2008

Spring 2005
Date-Rape-Drug Detection Device
Ale-No-More: The Beer That Prevents Hangovers
Biodiesel Fuel (before this became a commodity)
Teeth Whitening and Calcium Enriched Chewing Gum
Spring 2006
Photochromatic Automobile Windows
"Alledrex" – A Proposed Anti-Allergy Ocular Cream
Digital Price Display System for Stores
"Fizz" – A Sodium Bicarbonate-Citric Acid Tablet to Reinvigorate Partly-Consumed Bottles of Soft Drinks
Transdermal Patch for Delivery of Vitamins
Nanofluid Production by an Induction Heating Deposition Process
Spring 2007
Coated Dog Food for Outdoor Dogs
Aerosol Spray for Killing Salmonella
Transdermal Patch for Delivery of Thrombolytic Drugs
"Breath Assure" – A Litmus Test to Detect Bad Breath
Spring 2008
Refrigerator Cartridge for Absorption of Odors and Ethylene Gas
Biodegradable Cigarette Filter
"Vitamin Gum" – Get Your Daily Dose While You Chew!
Design of a Seamless Golf Ball
A Bite-size, Healthy, High-Protein Snack – An Alternative to Cereal and Protein Bars

1. DATE-RAPE-DRUG DETECTION DEVICE

(Donna H., Haymanot M, Cathy R., Erin W.)

This all-female team, obviously well attuned to the potential dangers lurking in singles bars, sought to design a cheap, effective and unobtrusive device to detect the presence of one or more date-rape drugs surreptitiously slipped into an alcoholic beverage. Research elicited that there are three often used such drugs in the US – Rohypnol, γ-Hydroxybutyrate (GHB) and Ketamine (US Department of Health and Human Services). Further research identified a number of chemicals that could detect one or more of these drugs by means of a color change or fluorescence generating reaction (Guerra et al., 2004).

Though some drug detection kits using some of these chemicals were currently marketed, they were neither inexpensive nor unobtrusive to use.

The students proposed designing a stirrer or "swizzle" stick that could be coated with the detector and sold cheaply, or even given away, by bars as a service to their customers. These could be customized by individual bars or clubs in the same manner that swizzle sticks are currently customized and indeed would differ from existing sticks only in their extra external coating. How to apply such a coating to sticks was investigated and seemed to be feasible using either dip-coating or spray-coating. Initial calculations showed favorable process economics with the cost of a single stick being in the 5 to 15 cent range, an amount easily absorbed into the price of a drink.

2. **Teeth Whitening Chewing Gum**
   (Andrew B., Kyoung L., Min K., Gordon S., Randy S.)

This enterprising all-male team focused on the rapidly growing field of teeth whitening to capitalize on the vanities associated with an aging baby boomer generation. Research showed a 6% annual growth rate in the confectionary chewing gum industry in the early 2000's with a steady growth of specialty gum products in the same period. This growth has continued to increase. Retail sales of gum are up by about 10% in the past year, while sugarless gum sales are up 18% (National Confectioners Association). In the early 2000's sales of tooth whitening aids had tripled, auguring well for the future of a marriage between the two products. They proposed using Xylitol as a low calorie alternative to sugar. Some studies have shown that Xylitol fights cavities and plaque in teeth and may also counteract some symptoms of osteoporosis and diabetes, other concerns of aging baby boomers.

Gum manufacture is well documented and includes steps for the insertion of various additives and flavorings (see for example Wikipedia, 2008). A very dilute solution of hydrogen peroxide (less than 1% by volume) was proposed as the whitening ingredient. Current over-the-counter whitening products use as much as 2-3% hydrogen peroxide, but such concentrations may lead to an offensive odor problem. The team suggests that users of their product can be exposed to the same net quantity of hydrogen peroxide by chewing more gum over an extended period. They estimate that a plant to produce 10,000 tons per year of gum would pay back in about 2.5 years and yield an internal rate of return of about 25%.

3. **Nanofluid Production by an Induction Heating Deposition Process**
   (Matthew C.)

The premise behind this project is that properties of materials may be enhanced by the addition of nanoparticles. Ethylene glycol impregnated with copper nanoparticles has been shown to have improved heat exchange capacity (US Department of Energy). Ethylene glycol with improved heat transfer characteristics would reduce the quantity of anti-freeze needed in an automobile radiator permitting smaller lighter radiators to do the same cooling as today's standard units. This in turn lightens the weight of the car, with the end result of improving fuel efficiency.

Building on the work of Kostic (2008) the student proposed a continuous process to vaporize copper into nanosized particles using an induction heater and then disperse these particles in ethylene glycol. Figure 3 illustrates the proposed design. The design showed reasonably good economics though some of the data seem unrealistic. However the project showed an impressively high level of critical thinking on the part of a student who had elected to perform the exercise on his own and who, up to then, had shown decidedly average performance in most of his coursework.

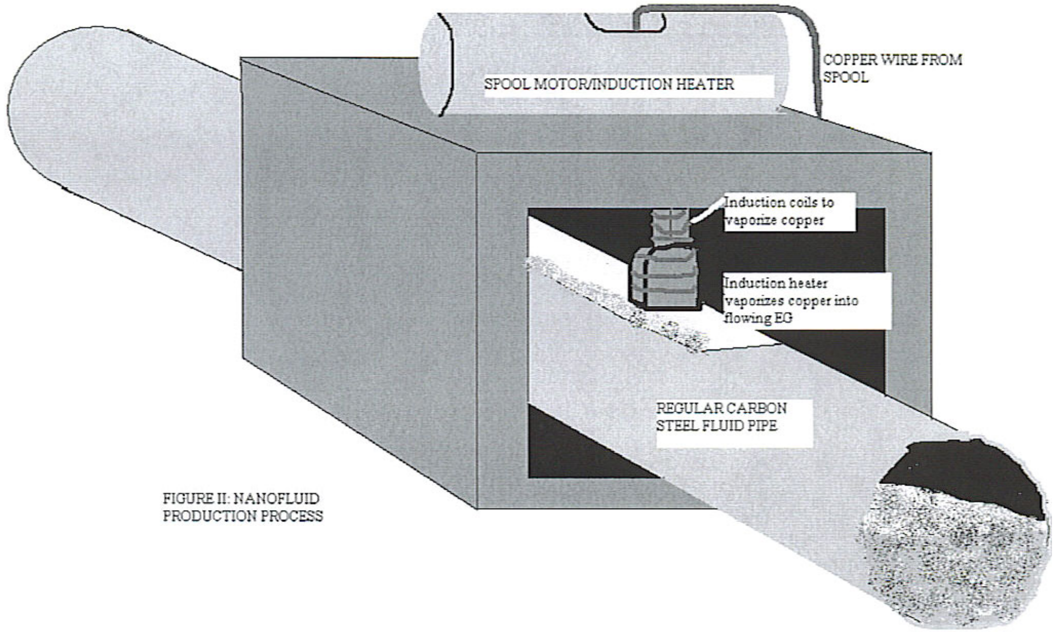

FIGURE 3: NANOFLUID PRODUCTION PROCESS

4. Design of a Seamless Golf Ball

(Nick C., Boris C., Dustin C., Devin C.)

This team of avid golfing enthusiasts, “The Four C’s”, proposed to design a better golf ball. Currently the top-selling golf ball on the market is the Titleist Pro V-1. It consists of a double layer core surrounded by a thin polyeurethane cover which is applied by encasing the core in twin hemispherical molds containing the liquid polymer. The mold surface is designed to form the polyeurathane into the conventional dimpled surface characteristic of a golf ball. However, the process creates a seam at the equator of the ball where no dimples are present and which causes the ball to have different flight characteristics depending on where it is struck relative to this seam. This concerns many professional golfers as it can mean a difference of up to 6 feet in a 250 foot drive.

Team 4C proposed an improved injection molding process whereby polyeurethane is injected into the mold via multiple ports (as opposed to a single port in the Titleist process) in such a manner that each half of the mold forms a fraction of a dimple at the points of contact between the top and bottom half of the ball. The result would be a complete set of whole dimples being formed where the seam formerly existed. The design is based loosely on a patent filed by Miller (1993). Miller’s design does not seem to have been put into production though he still owns the intellectual property and may have rights on aspects of the design proposed.

Preliminary economic analysis of a plant to produce 40 million golf balls per year shows a fixed capital investment of about $10 million, an ROI in the range of 50%, and a payback period of about 18 months, premised on making a golf ball for under $2 and selling it for about $4.50.

Discussion

The course has been conducted in the manner described for four years now. The projects performed by the students meet the level expected of senior chemical engineers in terms of the degree of rigor exhibited in the needs assessment, product selection, analysis of manufacturing criteria and economic projections. While some of the economic data seem overly optimistic many of the cost factors must be estimated from minimal available information. The students are forced to move beyond their comfort zone of readily available chemical or equipment cost data in publications such as ICIS Chemical Business (2008) or Peters et al (2001), the textbook currently used in CHE 471 and 572, and make informed estimates based on limited information. In addition most of the students find themselves dealing with synthesis and processing equipment that is widely different from what they normally encounter in traditional process design. This broadens their appreciation for what they may be called upon to work with in real life, and also builds their confidence that they can indeed work with the “unknown”.

Students have generally viewed the exercise favorably. There is an initial apprehension on the part of some students to seek out new ideas but usually one member of a team is adventurous enough to take on a leadership role in the early stages. Often this turns out to be one of the less academically strong students who perhaps was a Boy or Girl Scout in younger days and developed a desire to meet a challenge head-on, or an older student who has had broader life experiences than the norm. Once the idea for a new product has crystallized then the academically stronger students may take the lead in the actual design and “number-crunching” phase. Through this exercise all members of the team see the value of having different strengths represented when undertaking a project.

It is indeed very heartening to see the full maturing of students following four or more years of nurturing as they undertake and master a truly open ended challenge.

Conclusions

The author has successfully introduced a one-month module on Chemical Product Design based on the methodology proposed by Cussler and Moggridge (2001) into the second course of the design sequence at University of Louisville. Projects tend to be generally of acceptable quality and most students enjoy the challenge of a completely open-ended problem. After four years of refining the module, the concept is working to bring out a high level of critical thinking on the part of the students and to enhance their confidence in their technical ability as they move towards the world of work or graduate study.

Acknowledgement

JCW acknowledges the hard work of the University of Louisville BSChE graduates of 2005 to 2008. Without their willingness to take on the new challenge of Chemical Product Design this paper would not have been possible. May they have long, fruitful and productive lives and careers and may they never lose their willingness to meet a challenge head-on!

CHE 572 Plant, Process and Project Design SPRING 2008

Design Problem 2 Introduction to Product Design

You may do this problem individually, in groups of 3 or 4 or as a whole class. The goal is to produce a report on the design of a new or modified product that we will propose to management. Let me know on March 20 how people will work on the project. The steps in the process are as follows:

1. Identify a need. In the real world this would be done by interviewing customers and potential end users. It will also include a market analysis to determine potential number of end users, etc. In a class exercise it is up to you to come up with the need from your own devices and project the market needs. I have provided some ideas in the class and there are several in the Cussler book. You are also encouraged to suggest some of your own. Ideally what you propose should have some relationship to chemical engineering, engineering in general or chemistry.
2. Convert that need to Specifications for a product, chemical or device. Revise those specifications so that they are realistic, i.e., feasible at a "reasonable" cost, which is related to a price you would expect people would be willing to pay for your product.
3. Brainstorm ideas for your product. Ideally you should generate 100 +/- ideas. Sort and screen the ideas to about 5 viable ones.
4. Select one or two ideas for future research. Use scientific principles (thermodynamics, kinetics), subjective criteria and risk analysis to guide your selection.
5. Propose a manufacturing process for your product. Be aware of issues such as potential for patents or trade secrets, how to get "missing information", setting final specifications, and the need to be "first to market".
6. If your product involves the manufacture of a specialty chemical, be aware of the differences between commodity and specialty chemical manufacture – generic equipment, FDA/USDA issues for pharmaceuticals and food products, scale-up issues, etc.
7. Economics considerations – differences between commodity and specialty products such as generic equipment, shorter product sales life, etc.

Prepare a report that addresses the above issues, making a recommendation to proceed (or not) with manufacturing the product. A suggested report format is on page 2. Be aware that some of the items requested in the report may require estimation from few or no data – use your best engineering guesses.

Report is due by 9.30 am on Thursday April 17, 2008, last day of class for CHE 572.

FIGURE 1: CHEMICAL PRODUCT DESIGN ASSIGNMENT AS PRESENTED IN SPRING 2008

Format for Design Report 2

OUTLINE		Points
	Letter of Transmittal	5
	Title Page	5
	ABSTRACT (one page)	15
	SUMMARY (two or three pages)	30
	Table of Contents	
(1)	SCOPE: Identify the product, dimensions, raw materials, production rate,	10
(2)	Identification of Needs for your product	10
(3)	Ideas – lists of ideas generated by brainstorming; screening, sorting	10
(4)	Selection – selection process using objective criteria such as chemistry, thermo, etc; subjective criteria and how subjectivity was minimized using various selection matrices, etc.; risk management	10
(5)	Manufacture – filling in missing info; setting final specs; scale-up needed	10
(6)	IP issues (Patent, trade secret, other)	10
(7)	EQUIPMENT	10
	Equipment List	
(8)	ECONOMICS: Best estimate of as much as possible of	
	a. CAPITAL INVESTMENT	10
	Fixed Capital Working Capital Total Capital	
	b. Manufacturing COSTS	10
	Direct Manufacturing Costs	
	Indirect Manufacturing Costs	
	c. PROFITABILITY	10
	NPW	
(9)	CONCLUSIONS AND RECOMMENDATIONS	20
	Conclusions	
	Recommendations	
(10)	REFERENCES & BIBLIOGRAPHY	10
(11)	APPENDICES	15
	Supporting Documentation	
	Copies of most important references, etc.	
	Detailed calculations (MEB, Component Design, Financial)	
TOTAL		200

FIGURE 2: SUGGESTED OUTLINE AND POINT ASSIGNMENT FOR FINAL REPORT ON CHEMICAL PRODUCT DESIGN

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