INTRODUCING FRESHMAN ENGINEERING STUDENTS TO CHEMICAL PRODUCT DESIGN

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Abstract--*Historically, design courses in the chemical and environmental engineering curricula focus on teaching process design rather than product design. To meet consumer needs and keep up with industry's changing hiring practices and business models, products must be conceived and designed by multidisciplinary teams that include specialists from fields of engineering and business, fine arts and social sciences. If engineering students are to be ready to participate in product design, the curriculum must be adjusted to introduce product design.*

This paper describes an innovative effort to introduce freshmen engineering students to product design through reverse engineering. Three familiar commercial chemical products are used as a means of introducing the concepts of product design: beer, coffee and coffee makers, and water and water filters. Students analyze and evaluate commercial products through reverse engineering laboratory experiments. Through several other activities students investigate broader issues relevant to product design, including packaging, properties of consumer demands, intellectual property, ethics, environmental concerns, and marketing. Finally, students implement a general product design scheme to develop their own commercial product.

Index Terms: product design, freshman engineering, measurements and analysis

INTRODUCTION

Historically, design courses in the chemical engineering curriculum focus on teaching process design rather than product design. A traditional chemical engineering program may contain one or two design courses at the senior level. The first design course generally addresses the design of unit operations such as physical separators, distillation columns, heat exchangers, turbomachinery, and other process components. A subsequent capstone design course provides students with an excellent opportunity to combine what they have learned in previous courses such as thermodynamics, reaction engineering and transport phenomena. In the capstone design course, students' effort is usually geared towards the design of a process to manufacture a commodity chemical, such as cumene or styrene. This traditional design education was originated and driven by the needs of the chemical commodity industry that dominated the chemical industry during the twentieth century.

Recently, Cussler[1] indicated the importance of including product design in the chemical engineering capstone design course. His view is consistent with a new industry reality. The most traditional oil and chemical companies are introducing major changes to remain competitive, and in the US, new start-up companies, mostly in the product business, are constantly emerging. Cussler's[1] statistics also show that, in the last twenty years, more chemical engineering graduates go to work in companies that manufacture products rather than in traditional chemical plants. Westerberg and Subrahmanian[2] also address the importance of introducing product design in the chemical engineering curriculum and give a clear description of the differences between process and product design. The authors list the main characteristics that define a chemical product:

Products that are chemicals such as pharmaceutical drugs, proteins, pesticides, cleaning fluids,

Products that require chemistry in the manufacture process such as computer chips,

Devices that involve chemistry in their functionality such as asbestos removal systems, fuel cells, portable oxygen generator,

Products that are produced in small volumes and posses a high added value.

Such a product has to meet certain customer needs therefore it can only be conceived and designed by a multidisciplinary team that includes engineers and business, fine arts and social sciences specialists. If chemical and civil engineering students are to be ready to participate in product design, the curriculum must be adjusted to introduce product design.

At Rowan University, the first introduction to product design occurs in the Freshman Clinic, a two-semester sequence that introduces all freshmen engineering students to engineering. The first semester of the course focuses on multidisciplinary engineering experiments using engineering measurements as a common thread, and the theme of the second semester is the reverse engineering of a commercial product or process. Previous reverse engineering projects have involved products such as automatic coffee makers [3], [4], hair dryers [5] and electric toothbrushes [6]. Our incorporation of the design and reverse engineering of a process into our Freshman Clinic using the brewing process has been described previously [7]. Chemical product design has been a recent focus of the Freshman Clinic, and the first product design investigation focused on Beer [8]. The project described in

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this paper describes investigations of beer, water/water filters, and coffee/coffee makers to introduce product design to Freshman Engineering students.

BEER

Many properties are important in determining the overall character, flavor, and stability of a beer. Some of these properties may be evaluated by simple observation, while others can be evaluated only by using specialized instrumentation or chemical analyses. Described in this paper is our analysis of packaging material, the head stability, the color, the pH, the alcohol content, the sugar content, and the cost of three commercial beers. The relevance of these properties to the consumer's perception of the product, and experimental testing methods are described in detail by Farrell et al. [8]. We also consider the broader picture by addressing environmental issues and recycling, economics, marketing, and ethics.

During a three-hour laboratory period, students can reasonably analyze and compare three beers. In our laboratory, we analyzed several commercial beers but found the following best suited for student experiments: (1) Budweiser, an American lager which is quite light in color and is available in cans or brown bottles, (2) Bass Ale, a slightly darker English ale which is available in brown bottles, and (3) and Guinness Draught, an Irish stout ale that is packaged in an aluminum can with a widget. Guinness was chosen to provide the opportunity to explore the widget, stable foam, and small bubble flow; Bass Ale and Budweiser were chosen for the availability of published information on these products. This section describes the methods and results of the commercial beer analysis.

The experimental procedures used include several standard tests used in the brewing industry, modified as necessary to be performed in a student laboratory by individuals without specialized training. The results presented in this section are typical experimental results obtained by students in an educational setting rather than a research laboratory or a consumer testing facility. The results should not be interpreted to represent an endorsement of any brand name or particular product.

Packaging

Prior to opening the package, students should observe the packaging material, color, label information, and fill level. To gain an appreciation for the governmental regulations on labeling and advertising of alcoholic beverages, students researched the laws on labeling information for homework.

Head Retention

After opening the beer, the next step is to pour the beer and observe the foam stability or head retention. The time for a void to develop in a one-inch high foam is measured.

A good rule of thumb for head retention is given by Fix[9]: A one-inch head should last for five minutes without the appearance of voids (spots where the surface of the beer liquid is not covered by foam). Students use this guideline to evaluate the foam retention of their beer. The size and uniformity of the bubbles are also observed.

Color

There are several methods for measuring color in beer, two of which are used in this experiment. The first method uses a color comparison chart, called a Davison Color Chart (available for about $6.00 at local homebrew shops), to match the beer color to a standard color on the chart. The second technique is a spectrophotometric method called the Standard Reference Method (SRM), which uses a wavelength of 430 nm. Color is expressed in Lovibond (^{o}L). Student results of 2.5 ^{o}L for Budweiser, 12 ^{o}L for Bass, and 24 ^{o}L for Guinness compare well with the published from Fix [9] and shown in Table I.

pH

The pH of the beer can be analyzed using a pH meter or a pH test strip. The results are then compared to published values shown in Table I.

Alcohol Analysis

The alcohol content of the beer was analyzed using a YSI 2700 Biochemistry Analyzer. These results are compared to the estimated alcohol content using the specific gravity method, as well as published values in Table I.

The widget

The final step in the product analysis is to investigate the widget in the can of Guinness Draught. The Guinness can should be carefully cut apart using scissors. Inside the can is the plastic widget, which should be carefully examined. Students should look for the tiny laser-drilled hole, from which the liquid beer and gases rush out upon opening to induce nucleation by mechanical shear. For homework, students read the patent and learn more about how the widget works.

Cost

Through comparison of the different commercial beers gives students gain an understanding of the desireable properties that contribute to the overall quality of the product. An important factor closely linked with these properties is the cost. Students can obtain cost information on commercial beers in local newspaper advertisements and by calling local stores that sell beer. Bottles of Budweiser and Bass Ale are sold in 6-packs of twelve ounce containers, while Guinness Draught cans are sold in 4-packs of 14 ounce containers. Students obtain pricing information and calculate the unit price per ounce of their products. Typical results (for the Southern New Jersey area, and based a single pack) are: Budweiser - $0.063 /oz; Bass Ale - $0.111/ oz; Guinness Draught $0.116/oz.

Further Investigation

In addition to writing a laboratory report, the homework assignment and additional out-of-class activities include an investigation of the issues that contribute to the "broader picture" of product design: patents, environmental and recycling issues, marketing, government regulations and taxation, economics and ethics.

TABLE I.
BEER COLOR, PH, ALCOHOL CONTENT AND CALORIES

Beer	Color (Lovibond) [9]	pH [9]	Alcohol % by Volume (by Weight)[10]	Calories /100 ml [10]
Budweiser	2.0	~4.40	4.66 (3.73)	40
Bass Pale Ale	10.0	3.97	4.50 (3.60)	45
Guinness	~25.0	--	4.27 (3.42)	43

WATER

The Civil and Environmental Engineering Program at Rowan University introduced portable water purification units as a vehicle to introduce product design through reverse engineering to incoming freshmen [11,12]. Many sporting goods stores market reliable outdoor products for committed backcountry users to ensure safe drinking water. Although these products are not a common household item, they help to reinforce engineering design principles successfully. The water filters allow students to investigate the following topics inherent to the design of any product:

- Engineering Materials
- Manufacturing Processes
- Packaging
- Engineering Drawing
- Cost Analysis
- Microbiology
- Physico-Chemical Processes
- Environmental Considerations in Design
- Ergonomics
- Ethical Considerations in Design
- Environmental Regulations
- Life Cycle Management
- Safety
- Intellectual Property Rights

Project Details:

PuR, MSR and Sweetwater water filters are used by four teams of twenty students. Each team has a different model of the water filters, so that performance, features, costs and experimental results can be compared to evaluate the product. Students conduct both non-intrusive and intrusive testing on the filters to investigate the design of their product.

The initial weeks are focused on non-intrusive testing of the product. Students are asked to write a report that addresses following information:

- external dimensions
- list of parts with material identification
- function of each filter component
- common and special (safety, ergonomics and aesthetic) features of their product
- detailed AUTOCAD drawings of their product with proper dimensions and labels
- comments on intellectual property rights
- environmental considerations in design of the product (recylability, reuse etc.)
- literature survey of current water filters in the market
- deficiencies in product design
- improvements in overall design of the filter

The non-intrusive tests help students strengthen not only their technical communication skills but also helps students discover the engineering concepts that are behind the design of their product. The rest of the semester is spent on designing experiments to evaluate filter performance. Students identify parameters to evaluate water quality and the analytical techniques for measuring water quality parameters. Typical parameters that are measured are pH, alkalinity, turbidity, conductivity, organics and inorganics, bacteria etc. Flowrate and pressure are also identified as important operating parameters. Students analyze and plot data obtained from experimental runs and provide technical interpretations of their data. The entire exercise also exposes them to basic water treatment processes such as filtration, ion-exchange, disinfection and adsorption. Student teams also compare the performance of their water filters by sharing and comparing their experimental data.

This project is instrumental in exposing students to different engineering materials and their unique properties that allows for their use in engineering design. Plastics, resins, activated carbon, ceramics, polycarbonates, rubber and silicone are some of the materials that the students are exposed to through this excercise.

The entire semester long project culminates in a final report and formal presentation. The unique aspect of this entire project is the use of water filters to introduce the concepts of reverse engineering. Many schools have used various appliances such as toasters, hair dryers, coffee makers, electric drills etc. to introduce reverse engineering to students [13, 14]. The water filters spark the students' attention irrespective of their engineering choices because of the interest everyone has in drinking water quality. The fact that many students use these types of filtration units during camping and hiking expeditions also accounts for their enthusiasm to learn about the engineering principles involved in the design.

COFFEE

Many products designed by engineers are very complex and would require a large investment of time by students to familiarize themselves with the engineering principles employed in its design. Hesketh[15] and Hesketh and Slater [3] have shown how the novel use of an automatic coffeemaker dramatically reduces the time required for a student to assimilate the fundamentals of engineering processes. Since nearly every household owns a coffeemaker, the initial unfamiliarity associated with most industrial processes is absent in using the coffeemaker. This same theme can be used to show the design of the coffee maker as a product as well as the drink coffee as a product.

The coffee machine has examples from at least 8 engineering processes (Figure 1). These process operations are shown in above as; particle size reduction (grinding); tank efflux through a one-way valve; liquid heating in a tubular heater; upward two-phase flow in pipes; vapor condensation; liquid flow distribution and bypass; flow through a no-drip valve; leaching and filtration. Underlying these unit operations, there are fundamental principles of process engineering and engineering science such as: fluid flow - both single and 2-phase; heat transfer; thermodynamics ("engineering science" and equilibrium); mass transfer; particle technology; and general and organic chemistry. Detailed design topics such as materials of construction, engineering economics, process control, electronics and circuits are also shown using the coffee machine. Novel environmental aspects of this process such as waste energy

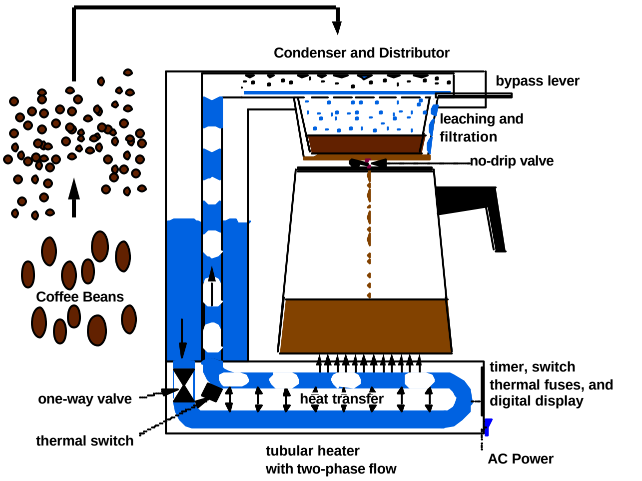

FIGURE 1
UNIT OPERATIONS USED IN THE COFFEE MAKER

and materials minimization can be analyzed.

A unique series of cost effective experiments used successfully at the Freshman level at Rowan University [4,5,16,17,18] is based on the coffee maker. In the spring semester, a section of freshman students devote an entire semester reverse engineering a coffee maker. These laboratories allow the student to explore the design of the coffee maker as a product as well as coffee, the drink, as a product.

This Freshman Spring semester contains faculty led experiments and student designed experiments. The faculty led experiments consist of a series of non-intrusive experiments. In the non-intrusive experiment students measure the electrical power delivered to the coffee maker; the temperature of the liquid in the feed tank, exit of the leaching unit and the coffee carafe; the flowrate from timed volume readings on the side of the reservoir; the maximum volume of water in that the carafe will hold; and the amount of coffee grounds and particle size that will cause the filter to overflow. In a related measurement they determine how long the no-drip valve can be engaged before the filter will overflow (about 1 minute). The second series of faculty driven experiments examine the rate of leaching of coffee. The effect of water temperature, particle size and concentration driving force was examined (Figures 2 and 3). Concentrations were determined from absorption measurements from a spectrometer and a data acquisition system. In a third set of experiments students examine the fluid mechanics by observing the two phase flow within a clear plastic riser tube; the function of the one-way valve; and measure the flowrate indirectly from pressure measurements in the reservoir. These experiments are relatively inexpensive and only require a $20 coffee machine and typical laboratory equipment.

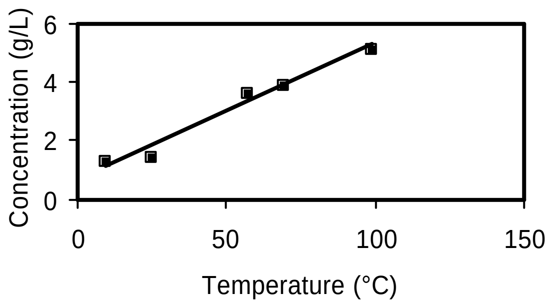

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FIGURE 2
EFFECT OF TEMPERATURE ON COFFEE CONCENTRATION

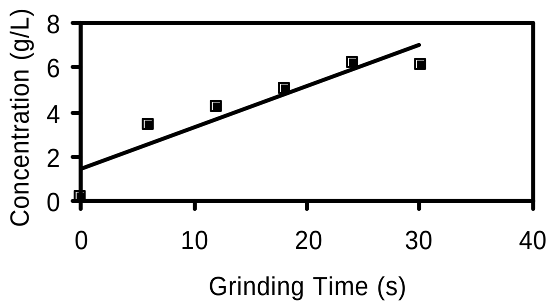

FIGURE 3
EFFECT OF GRINDING TIME ON COFFEE CONCENTRATIONS

The student driven and designed experiments start with dissection studies and culminates in a completely instrumented coffee maker. The destructive experiments start by having the students take apart a coffee machine. A basic requirement for this activity is to obtain a screw driver set with security bits! Students examine the operation of thermal and electric switches, one-way valves, bypass valves, and no-drip valves. They measure the resistance of the tubular electric heater and cut them open to examine the coiled Nichrome wire. This experience ends with students placing thermocouples throughout the coffee machine, using a pressure transducer to measure pressure in the feed tank and a wattmeter to measure power to the coffee machine. All of these devices are connected to a computer controlled data acquisition system. The instrumented coffee machine experiment requires data acquisition boards, thermocouples, pressure transducers, wattmeter and a computer. The estimated cost of the setup is $2,500 excluding the computer.

CONCLUSIONS

Commercial beer, coffee, and water have been used as a means of introducing freshman to the concept of product design. Issues relevant to product design have been addressed including packaging, properties of interest to consumers patent information and the importance of marketing the product. Student feedback indicates that this approach is well-received by the students and presents a first opportunity to consider the design of a chemical engineering product. Student comments indicated that the most important things learned in this course were teamwork, presentation skills, the interdependence of engineering and marketing, and the relevance of broader issues such as intellectual property and ethics to product design. With all three products, students expressed an interest acquiring more in-depth knowledge about the product and the process used to make it.

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