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Introducing Freshmen to Reverse Process Engineering and Design Through Investigation of the Brewing Process*

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Freshman engineering students at Rowan University are introduced to engineering design through a series of hands-on engineering and design projects. These design experiences in the first semester are incrementally progressive; their purpose is to lead the students into the second semester and a single, in-depth, reverse engineering project.. Previous projects have included the dissection of several inexpensive commercial products such as coffeemakers, toothbrushes, water purifiers, and hairdryers. This paper describes our effort to introduce reverse engineering and design of a process into the course. The focal point is a laboratory project in which students investigate a process for the production of beer. After a brief introduction to the brewing process and a comparative technical evaluation of commercially available beers, the students set out in teams to perform a hands-on, reverse-engineering investigation of the fermentation process and home-brewing equipment. Next, each team plans a commercial venture involving the brewing process. The teams plan their ventures (which may range from a brewery or restaurant to a full-scale brewery and distribution network), and present their designs and a marketing plan to the other groups. The brewing process introduces freshman students to engineering fundamentals related to material balances and stoichiometry, fluid flow, heat and mass transfer, and biochemical reactions. This project, meets several educational objectives: to develop creative and critical thinking, to introduce design principles, to provide hands on experience, to develop teamwork and communication skills, and to stimulate enthusiasm for engineering.

INTRODUCTION

ROWAN UNIVERSITY is pioneering an engineering program that uses innovative methods of teaching and learning to prepare students better for a rapidly changing and highly competitive marketplace, as recommended by the American Society for Engineering Education [1]. Key features of the program include:

- multidisciplinary education through collaborative laboratory and course work;
- teamwork as the necessary framework for solving complex problems;
- incorporation of state-of-the-art technologies throughout the curricula;
- creation of continuous opportunities for technical communication [2].

The Rowan program emphasizes these essential features in an eight-semester, multidisciplinary Engineering Clinic sequence that is common to the four Engineering programs (Civil, Chemical, Electrical and Mechanical).

A two-semester Freshman Clinic sequence introduces all freshmen engineering students to engineering at Rowan University. In the Freshman Clinic we immediately establish a hands-on, active learning environment for the reason explained by scientist and statesman Benjamin Franklin:

> *'Tell me and I forget. Show me and I may remember. Involve me and I understand.'*

The first semester of the course focuses on multidisciplinary engineering experiments using engineering measurements as a common thread.

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 [3–5], hair dryers and electric toothbrushes [6]. This paper describes our first effort to incorporate the design and reverse engineering of a process into our Freshman Clinic. We focus on the investigation of the beer production process.

In the first half of the semester, students work in multidisciplinary teams to 'dissect' the brewing process. Through this they discover how the design of a process is impacted by scientific principles, material properties, manufacturing techniques, cost, safety requirements, environmental considerations and intellectual property rights In the second half of the semester, students participate actively in a meaningful design effort by designing their own commercial endeavor using

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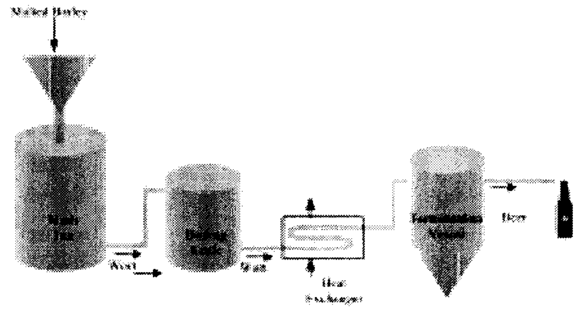

Fig. 1. Schematic representation of the brewing process showing the major process steps.

the brewing processes. The project offers an opportunity to focus on the development of technical communication skills as well as the improvement of time management and critical thinking skills.

THE BREWING PROCESS

The students' investigation focuses on three of the major steps of the brewing process:

- mashing
- boiling
- fermentation.

During mashing, milled barley is incubated with warm water for approximately one hour. During this time, some enzymes present in malted barley break down starches into fermentable sugars, and other enzymes break down proteins to form amino acids. These nutrients extracted from the barley form a nutritionally complete wort. After the solid barley separates, the liquid solution is then fed to a kettle and boiled with hops, (a dried flower that imparts a characteristic bitter flavor), for about 15–30 minutes. Filtration later removes the hops from the liquid, which is then chilled and fed to the fermenter before adding the yeast. During fermentation, yeast converts sugar to alcohol and carbon dioxide, and after several days the product is beer. Figure 1 shows the brewing process.

Table 1. Engineering and scientific principles and topics related to beer production

Principle/Topic	Where Applicable
Heat Transfer	Mashing, Boiling, Chilling
Mass Transfer/Separations	Filtration after mashing and boiling
Vapor-Liquid Equilibrium	Carbonation
Fluid Flow	Tank drainage
Stiochiometry and Material Balances	Fermentation
Chemical Reaction Kinetics	Fermentation
Material Compatibility	Packaging (bottles, cans)
Economics	Entire process
Electronic Data Acquisition	Monitoring temperature and CO_2 evolution during fermentation
Environmental Issues	Recycling of cans and bottles

The brewing process involves several engineering and science principles such as fluid flow, heat transfer, stoichiometry and material balances, and chemical reaction kinetics. Additionally, the project incorporates topics such as material compatibility, engineering economics, electronics and circuits, and environmental issues. Table 1 shows some of these principles and topics, and some of the process steps to which they are applicable.

THE PROJECT STRUCTURE

Developing a scheme to perform reverse engineering on a process to produce beer presents an interesting challenge. While scientists have recently made great strides toward understanding the chemistry of brewing, brewing is still largely a craft. Still, we can approach the brewing process from an engineering perspective by investigating the effects of process operating variables on the properties of the end product.

As the basis of the structure of this project, we used the course structure from the reverse engineering of products. The previous reverse engineering investigations of consumer appliances began with a study of the product operation through non-intrusive testing. Following this, a more in-depth product dissection took place, involving analysis of the mechanical systems and materials of the product. Next, students proposed and implemented experiments to investigate the details of the product operation by intrusive testing of the electrical and mechanical systems. Finally, they proposed improvements to their products.

To conduct a reverse engineering investigation of our brewing process, we devised a structure that is analogous to the reverse product engineering structure described above. Students begin by investigating the end product through an evaluation of several types of commercially available beer. This parallels the non-intrusive product testing described above. Next, students 'dissect' the brewing process as they explore some of the biochemical changes that take place during brewing by performing and analyzing the mashing and fermentation process steps. After a plant trip to a

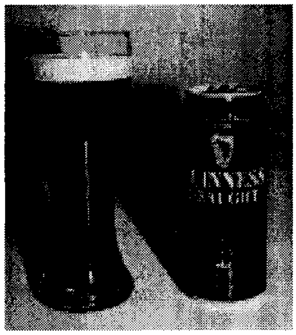

Fig. 2. The stable foam of Guiness Draught.

local microbrewery where students see the brewing process in action, they design and a commercial venture using the brewing process. Finally, they present a detailed technical and marketing plan for their operation.

NON-INTRUSIVE TESTING

Students begin their non-intrusive testing by studying a commercially available version of the end product. They perform qualitative and quantitative analyses on several types of beer:

- an alcohol-free beer such as O'Douls
- a straw/gold pilsner such as Budweiser
- an amber beer such as Bass Ale
- a dark beer such as Guinness Stout.

Each team of four students evaluates samples of each type of beer. Students begin by observing several properties of each product:

- the liquid level in the bottle
- the bottle color
- the sound the beer makes upon opening
- the size and fullness of the head upon pouring
- the head retention
- the smell, color and apparent carbonation.

Several texts discuss the relevance of each of these properties [7–10]. Next, the students quantitatively analyze several properties of each type of beer; they test:

- head retention
- alcohol content
- sugar content
- color
- pH.

Opening a can of Guinness Draught is an exciting experience, particularly for the unsuspecting student! The Guinness can contains a proprietary widget that induces the sudden and dramatic production of foam upon opening of the can. Guinness is pressurized with nitrogen and carbon dioxide; the nitrogen creates a very stable foam with tiny bubbles, as shown in Fig. 2. It is interesting to compare this foam to the foam on one of

Fig. 3. Guinness' proprietary widget, US Patent No. 4,832,968.

the other commercial beers, as the difference in bubble size and foam retention are significant. After students cut open the can of Guinness to discover the widget inside as shown in Fig. 3, they must work out how the widget works. An observant student will discover that US Patent number 4,832,968 is cited on the can—this is the patent for the widget [11]. Reading the patent enables students to learn how the widget works, and introduces them to intellectual property rights in the brewing industry.

PROCESS DISSECTION: MASHING AND FERMENTATION

Students perform mashing and fermentation to investigate some of the biochemical changes that occur to convert barley to beer. They start by making beer from a malt extract kit. Producing beer from a malt extract kit is very simple; heat the malt extract, boil for 15 minutes, then transfer to a fermentation vessel (Erlenmeyer flask) and dilute with cool water before adding yeast. The fermentation process takes place over the next 8–14 days, with the most vigorous fermentation occurring within the first 3 days. Using the malt extract kit eliminates the necessity to perform several process steps before the fermentation, enabling students to focus on understanding the fermentation step.

The first time the students implement the fermentation process, they evaluate the process primarily through visual observation and try to answer several questions.

1. Is there a color change in the liquid during the fermentation process (measured using a Davison color chart)?
2. How long does it take the fermentation to become vigorous?
3. What is the approximate duration of the vigorous fermentation?
4. Is there evidence of yeast growth or turbidity during the process?
5. Is the yeast distributed at the top, throughout, or at the bottom of the liquid?
6. Does the yeast begin to settle at any time during the process?

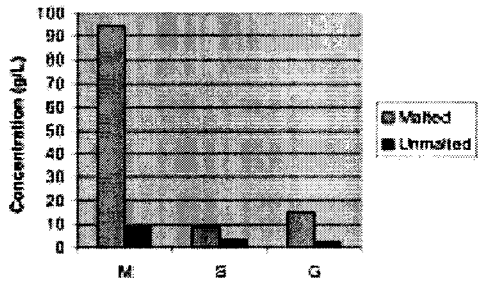

Fig. 4. Fermentable sugars in the wort from malted and unmalted barley.

After completion of the fermentation process, students analyze their beer using the methods described above.

Next the students investigate the mashing step. The mashing step immediately precedes boiling and fermentation in the brewing process, and it is the step that produces a nutritionally complete wort for fermentation. Students mash both malted barley and unmalted barley, and they compare the worts obtained from each type of barley. Analyses of the total extract and concentrations of fermentable sugars reveal that only the malted barley produces a wort containing fermentable sugars. The reason for this is that malted barley contains enzymes necessary to convert starches to fermentable sugars, and unmalted barley does not. Figure 4 compares the amount of fermentable sugars (maltose, glucose and sucrose) present in the wort after mashing of malted and unmalted barley. A commercial enzyme test kit enables measurement of individual sugar concentrations. If the enzyme kit is unavailable or the cost of the kit is prohibitive, measurement of the glucose concentration is possible using a home glucose test kit, used by diabetics to measure blood glucose levels. These meters and test strips are inexpensive and sold at most pharmacies.

MARKETING EXERCISE

Student teams brainstormed issues that would have an impact on the formation of a commercial brewing venture. Their ideas included:

- start-up capital
- advertising and brand-name recognition
- distribution issues
- technical issues of the brewing process
- environmental and regulatory issues.

The majority of teams chose to market a brewery or restaurant, while a minority of groups chose a microbrewery/bottling facility. Each team designed a label, marketing slogan, proposed methods of obtaining start-up capital, and formulated the technical details for their brewing processes. Teams made group oral presentations to the other teams and faculty. The students reported that this part of the project was among their favorite parts of the course and helped draw the technical details together with the business-oriented aspects of engineering design.

SUMMARY

The investigation of the brewing process in our Freshman Clinic was an effort to perform reverse engineering of a process. The course structure followed a similar structure similar to that used for the reverse engineering and competitive assessment of consumer appliances. Beginning by evaluating commercial beers, students proceeded to dissect steps of the brewing process. Students then designed a business using the brewing process, and finally suggest marketing strategies for that business.

The teams of students meet several educational objectives as they work through the various phases of this project. Students are introduced to engineering design concepts that involve heat transfer and mass transfer when they design the mashing, boiling, and chilling equipment. The fermentation process introduces the principles of stoichiometry, mass balances, and reaction kinetics. Students gain hands-on experience in reverse engineering commercial home-brewing equipment, implementing the process, and monitoring the fermentation. Frequent written progress reports, a final written project report, and midterm and final oral presentations place emphasis on communication skills.

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