

## **A LABORATORY PROJECT TO DESIGN AND IMPLEMENT A PROCESS FOR THE PRODUCTION OF BEER**

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### **Abstract**

This paper describes a one-semester Freshman Engineering Clinic Course that is being implemented at Rowan University in the Spring of 1999. The focal point of the course 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 evaluation of commercially available beers, the students set out in teams to perform a hands-on, reverse-engineering investigation of the fermentation process. Next, each team works on the design and construction of a brewing process. The teams implement their processes, and present their designs and results to the other groups. Finally, each group performs a comparison and evaluation of the designs.

The brewing process is used to introduce freshman students to engineering fundamentals related to material balances and stoichiometry, fluid flow, heat and mass transfer, and biochemical reactions. Through this project, several educational objectives are met: 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 a progressive and innovative 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 ASEE [1]. Key features of the program include: (i) multidisciplinary education through collaborative laboratory and course work; (ii) teamwork as the necessary framework for solving complex problems; (iii) incorporation of state-of-the-art technologies throughout the curricula; and (iv) 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

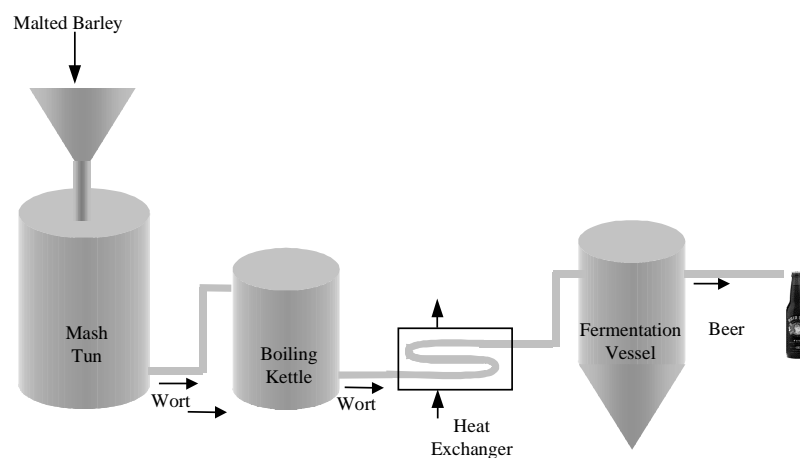
engineering measurements as a common thread. The theme of the second semester is the reverse engineering of a commercial product or process. Previous reverse engineering projects have involved products such as automatic coffee makers [3, 4, 5], hair dryers and electric toothbrushes [6]. This paper describes 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.

A project introduced in a three-week program sponsored by the National Science Foundation in 1990 was the inspiration for this project. The program, Exploring Career Options in Engineering and Science at Stevens Institute of Technology, was designed to stimulate enthusiasm for engineering and science among high school girls. The Chemical Engineering portion of this program, in which students designed a process to produce beer, was met with overwhelming excitement. The educational objectives of the design and reverse engineering project are to:

- Foster creative thinking
- Develop critical thinking
- Introduce engineering, scientific, and design principles
- Provide hands-on experience
- Develop communications and teamwork skills
- Stimulate enthusiasm for Engineering

## The Brewing Process

There are three major steps involved in the brewing process: mashing, boiling, and fermentation. Milled barley is fed to a mash tun where it is mixed with warm water and incubated for approximately 20 minutes to 2 hours. 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. Sugars, proteins, amino acids, and vitamins are extracted from the barley to form a nutritionally complete wort. The solid barley is then separated from the liquid solution, which is then fed to a kettle and boiled with hops for about 15 - 30 minutes. Hops, the dried female flowers of the hop plant, impart the characteristic bitter flavor to beer and have a bactericidal effect. Later they are removed by filtration from the liquid, which is then chilled and fed to the



**Figure 1 Schematic representation of the brewing process showing the major process steps**

fermenter. After several days of fermentation, the product is beer. The brewing process is shown in Figure 1.

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

**Table 1 Engineering and scientific principles and topics that are related to beer production**

<b>Principle / Topic</b>	<b>Where Applicable</b>
Heat Transfer	Mashing, Boiling, Chilling
Mass Transfer	Filtration after mashing and boiling
Fluid Flow	Tank drainage
Stoichiometry And Mass Balances	Fermentation
Chemical Reaction Kinetics	Fermentation
Material Compatibility	Packaging (bottles, cans)
Economics	Entire process
Electronics Data Acquisition	Monitoring temperature and CO <sub>2</sub> evolution during fermentation
Environmental Issues	Recycling of cans and bottles

### **The project structure**

The laboratory project structure can be broken down into four components. Students begin by investigating the final product through an evaluation of several types of commercially available beer. This gives students a perspective for the remainder of the project. Next, students 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 local microbrewery where students see the brewing process in action, they design and build the equipment and instrumentation for the brewing process (focusing on the mashing, boiling, chilling and fermentation steps). The final phase of the project involves implementation and monitoring of the process.

### **Evaluation of Commercial Beer**

Students begin 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, and 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. The relevance of each of these properties is discussed in several texts [7, 8, 9, 10]. Next, the students quantitatively analyze several properties of each type of beer: they test head retention, alcohol content, sugar content, color, and pH. The properties analyzed and the methods of analysis are summarized in Table 2.

**Table 2 Qualitative and Quantitative Analyses Performed on Beer**

Beer Quality	Qualitative Evaluation	Quantitative Method
Liquid level	✓	Ruler (distance from top)
Bottle color	✓	
Sound upon opening	✓	
Size and fullness of head	✓	
Smell	✓	
Color	✓	Spectrophotometer
Apparent carbonation	✓	
Alcohol content		Hydrometer; alcohol enzymatic test kit
Sugar content		Glucose-Sucrose-Mannose enzymatic test kit
pH		pH meter

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 Figure 2. It is interesting to compare this foam to the foam on one of 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 Figure 3, they must figure out how the widget works. An observant student will discover that U.S. Patent number 4,832,968 is cited on the can -- this is the patent for the widget [11]. By reading the patent, students learn how the widget works, and they are introduced to intellectual property rights in the brewing industry.



**Figure 2 The stable foam of Guinness Draught**



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

## How are barley and water converted to beer?

Students perform mashing and fermentation to investigate some of the biochemical changes that occur to convert barley to beer. We start by making beer from a malt extract kit. Producing beer from a malt extract kit is very simple; the malt extract is heated and boiled for 15 minutes, then transferred to a fermentation vessel (Erlenmeyer flask) and diluted with cool water before yeast is added. 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. Is there a color change in the liquid during the fermentation process? How long does it take the fermentation to become vigorous? What is the approximate duration of the vigorous fermentation? Is there evidence of yeast growth or turbidity during the process? Is the yeast distributed at the top, throughout, or at the bottom of the liquid? Does the yeast begin to settle at any time during the process? After completion of the fermentation process, students analyze their beer using the qualitative and quantitative 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.

## Design of the Brewing Process Equipment



Figure 4 Iron Hill's Mash Tun

After performing the brewing process using standard laboratory glassware, students begin to think about designing specialized equipment for the brewing process. We begin by making a field trip to the Iron Hill Restaurant and Brewery in West Chester, PA, a microbrewery that produces 300-Gallon batches of beer and uses seven different fermenters. Iron Hill's mash tun is shown in Figure 4. Mark Edelson, a co-owner of this business who has extensive brewing experience, guides the students through the brewery, explaining the different process steps. Mr. Edelson is a chemical engineer who gained extensive experience in manufacturing before founding the brewery. The students must note the important process measurements taken at the brewery, and gather important information about the equipment that will help them with the design of their own brewing process.

Next the students design and build the equipment for the

mashing, boiling, chilling and fermentation process steps, working within a budget of \$50. They may use or adapt items commonly available at department or hardware stores, but they may not use equipment specifically made for homebrewing.

There are several considerations for the design of the mashing equipment: how to maintain the desired temperature range for enzyme activity for the duration of the mashing process; how to remove the grist (spent barley grains) from the malt wort after mashing; and how to leach out the remaining sugars from the grist. Maintaining the temperature may be accomplished by manual on-off temperature control, or by using insulation. The grist may be removed by using a strainer, a pot with a “false bottom” such as a spaghetti pot, or by containing the grist in a mesh or cloth sack.

For the boiling and chilling steps, students must consider how to prevent the hops from clogging the system when draining the kettle (this is an issue if tubing is used in a gravity flow system). Other considerations involve cooling the wort before the fermentation. Yeast cannot be added until the temperature of the liquid is sufficiently low (below about 25 °C). As the wort cools, it becomes susceptible to contamination. Thus it is desirable to cool the wort rapidly and minimize exposure to the atmosphere. Ideally, the wort is cooled by flow through tubing as it drains from the boiling kettle to the fermentation vessel; this minimizes the exposure to the atmosphere. The tubing may be submerged in a bucket of cool water, and the tubing must be long enough to achieve the desired cooling. Cooling may be further enhanced by flowing cool water through the bucket.

For the fermentation process, consideration must be given to monitoring the biochemical changes that take place as the yeast convert sugar to alcohol and carbon dioxide. This reaction is accompanied by a decrease in pH and an evolution of heat. A possible scenario for monitoring the fermentation process is shown in Table 3. In this scenario, the temperature, pH, sugar concentration, alcohol concentration, and carbon dioxide evolution are measured; a more in-depth investigation would include measurement of dissolved oxygen and biomass accumulation.

**Table 3 Process variables monitored during the fermentation**

<b>Process Variable</b>	<b>Method</b>	<b>When monitored</b>
Temperature	Thermocouple; data acquisition	Continuously
Sugar concentration	Glucose-Sucrose-Mannose enzymatic test kit	Initial, final
Alcohol Concentration	Hydrometer; alcohol enzymatic test kit	Periodically
pH	pH meter, pH paper	Periodically
Carbon dioxide evolution	Flow meter or water displacement	Periodically

## **Implementation of the Brewing Process**

The culmination of the project is the implementation of the brewing process. During the final weeks of the process, students produce beer from malted barley using the process equipment that they design and built themselves. They monitor the fermentation as it proceeds to produce ethanol and carbon dioxide from sugar, and collect data that reveals the progression of the reaction.

## **Evaluation of the Process Design**

After the teams have implemented their process and product, they prepare written reports and present their results orally to the other teams. Each team must describe its process design and discuss how specific design considerations were addressed. They evaluate the strengths and weaknesses of their design, and suggest possible modifications and improvements to the process and equipment. The teams then have an open discussion in which they compare and evaluate the designs of the other teams. The teams follow up with a written summary of these process evaluations and comparisons.

## **Summary**

As the teams of students work through the various phases of this project, several educational objectives are met. Students think creatively to make an original design for their brewing process, and they use critical thinking to compare and evaluate their designs. They are introduced to engineering design concepts that involve heat transfer and mass transfer when they design the mashing, boiling, and chilling equipment. Principles of stoichiometry, mass balances, and reaction kinetics are introduced via the fermentation process. Students gain hands-on experience in building their own equipment, implementing the process, and monitoring the fermentation. Communications skills are emphasized with the final oral reports, written reports and the discussion of designs afterwards. Based on the demonstrated success of the three-week brewing project we are optimistic that the semester-long brewing project at Rowan University will enjoy the same success as measured by students' excitement and enthusiasm.

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