Welcome to ChE: Chocolate Engineering

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Abstract

An Introduction to Chemical Engineering course must introduce the student to the language of chemical processes as he learns of the many career options. This must be accomplished in a way that is meaningful to a student with minimal technical background and motivating enough to encourage them to return for another semester. The authors have found that food and fun are excellent motivators with chocolate being a distinct favorite.

The freshmen at The University of Tulsa learn about chocolate processing and have the opportunity to sample along the way. Groups of students can roast cocoa beans, break the beans apart and separate the edible portion from the husks, grind the beans, separate the cocoa butter from the solids, and attempt to make edible chocolate. Each step presents unique challenges to the students and encourages them to brainstorm ways to automate and scale up the process. The lessons learned during the freshman year are continued as the sophomores are introduced to mass and energy balances. There the emphasis is on the final products: chocolate covered cookies and chocolate covered coffee beans.

The students have an opportunity to demonstrate the lessons learned at the annual e-week Open House for middle school students. University students discuss the food processing steps and relate them to chemical engineering processes. Samples of the cocoa beans at different stages of processing are available to see and smell. The middle school students learn about the product specifications for white, milk and dark chocolate then choose a kind to sample. This activity combines the fun with the familiar as a useful reinforcement for the university students and an introduction of younger students to a career they might have never before considered.

Background

Chocolate has been a favorite food for many over the past 4000 years. Originally the cacao tree was cultivated by the Olmec and Aztec in the Yucatan Peninsula and the beans were used as currency. The Maya eventually developed a process of fermenting, drying and roasting the beans then grinding the nibs to create the chocolate liquor that is the basis of the chocolates we enjoy today.

The early consumption of chocolate in Central and South America was as a bitter drink blended with chili pepper. When Christopher Columbus brought this novelty to Spain in 1502 it was largely ignored, but eventually the Spanish began adding vanilla, sugar, cinnamon, and beer or wine. This concoction was so popular that it spread throughout Europe and earned a reputation as an aphrodisiac. It was not until Sir Hans Sloane added milk to his cocoa drink in the 1680's that the chocolate we know and love was created. This drink was served in

chocolate houses throughout England in the 17th and 18th centuries and nearly put the traditional English pub out of business[1].

The chocolate bar was not developed until J.S. Fry and Son mixed sugar and cocoa butter with chocolate powder to create a solid slab. This 1847 creation had a grainy texture and lacked the smooth flavor of today's chocolates. In 1876, Henri Nestle and Daniel Peters added milk and extra sugar to Fry's bar to create the first milk chocolate bar. Milton Henry became the first to mass produce milk chocolate bars in 1894.

Today cacao trees are grown around the world in tropical jungles. The trees produce melon-like pods which must be harvested by hand. These pods each contain about 20 – 40 seeds which are the cocoa bean. In 1990, 2.4×10^6 tons of cocoa beans were produced and 280,000 tons were consumed in the U.S. alone[2].

The cocoa beans are processed in a manner similar to that used by the Mayans 2500 years ago[2,3]. The beans are allowed to sit in piles in the sun for about a week to ferment. This allows the shells to harden, the beans to darken and the cocoa flavor to begin developing. At this stage they are moved to a chocolate factory where they are cleaned and stored. The beans are then roasted in large revolving roasters for 30 – 60 minutes at 70 – 180^{o}C. Many reactions occur during this step which remove the volatile acids, break down the sugars, modify the tannins and other nonvolatile compounds and convert the proteins to amino acids which develop the flavor compounds. The roasted beans are then moved to the winnowing process which removes the shell from the nibs. The nibs are sent to mills that grind them into a liquid called chocolate liquor. This liberates the fat that is locked into the cell walls and creates a smooth, dark liquid. The cocoa butter is removed from this chocolate liquor at a using a 34 MPa press. The remaining solids are pulverized to create the cocoa powder.

Consumer chocolates may be broadly classified as white chocolate, milk chocolate or dark chocolate. The FDA standards for these were established in 1944[4]. White chocolate contains only cocoa butter, no cocoa powder. Milk chocolate contains about 10% chocolate liquor plus added cocoa butter. Dark chocolate contains about 40% chocolate liquor with very little added cocoa butter.

The industrial process for making chocolates is well developed (see Figure 1[5]). The chocolate is first conched to ensure a smooth texture with proper particle sizes. This process involves mixing and shear of the chocolate under well-controlled conditions. The chocolate is then tempered (heated and sheared) so that the solid product has the most appealing crystal structure. Chocolate is a polymorphic solid[6]. Without this tempering step, the chocolate will have a Form IV structure which has a low melting point (27.3^{o}C), feels gritty and is not glossy. Tempered chocolate forms a Form V structure which melts at 33.8^{o}C, feels smooth, shrinks as it cools and has an attractive gloss.

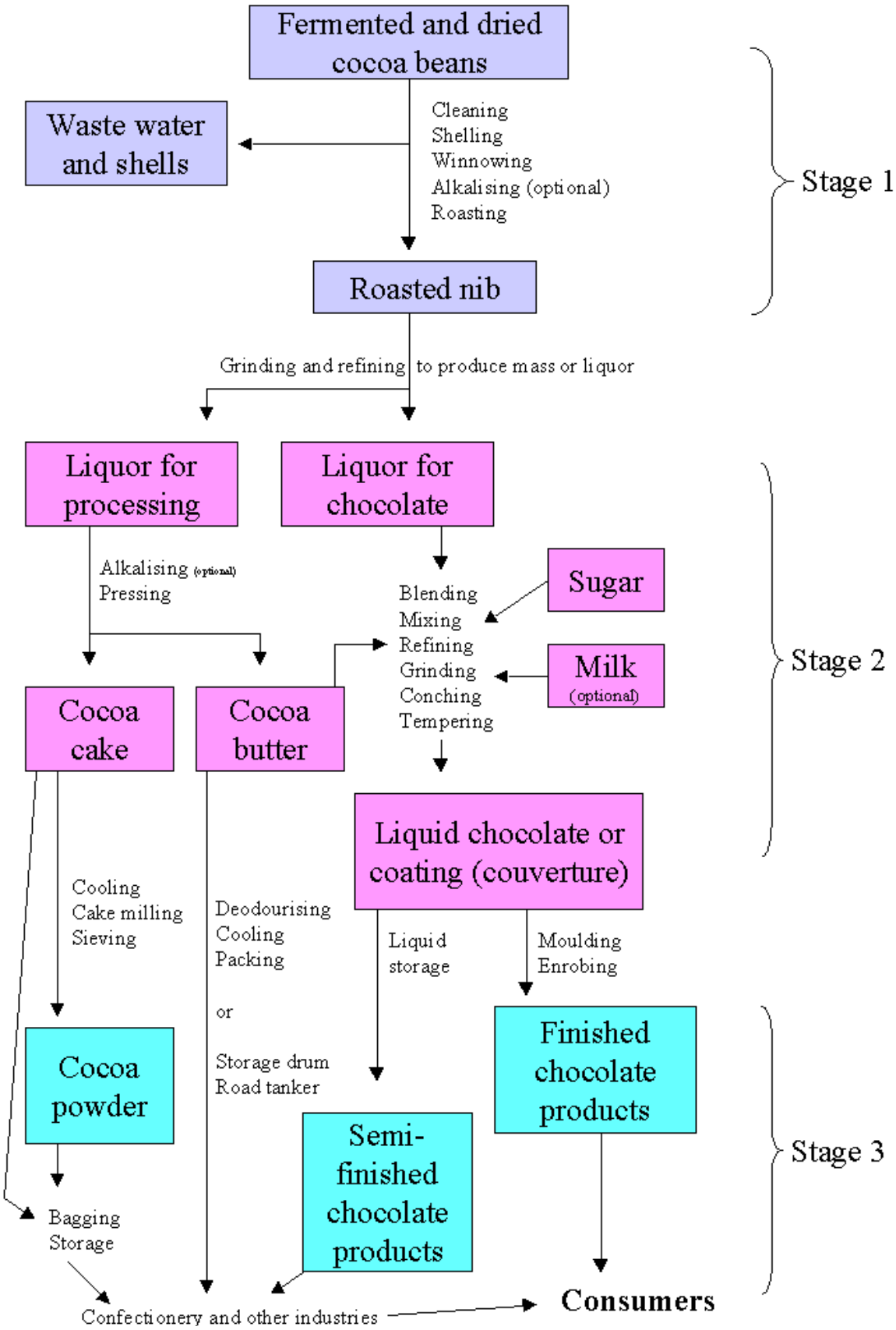

Figure 1. Flowchart for processing fermented cocoa beans to products[5].

Applications to the Chemical Engineering Curriculum

Many of these processes are quite similar to traditional chemical engineering processes: heat transfer, solids processing, mixing, and packaging. These processes are also cooking, and as such can be done at home in a well-supplied kitchen. During the freshman year at The University of Tulsa, the students attempt to process chocolate using basic kitchen appliances with steps inspired by the Chocolate Alchemist[7]. These steps are described in the next several paragraphs.

Fermented and dried cocoa beans are not available locally in our medium-sized city, but they are available at various internet vendors (search for raw cocoa and raw cacao). To produce the roasted nib, the beans must be roasted, cracked, and winnowed. Roasting can be done in a kitchen oven or hot air popcorn popper or with a hair dryer. The beans are roasted for 5 – 35 minutes at 250 – 325 ºF[7], starting with a high temperature and cooling during the roasting period. The goals are roasting the cocoa bean and loosening the husk from the nib. The roasting is done when the husks are cracked and the chocolate still smells good (no burnt smell). The students are given their choice of equipment and a pound of fermented beans to roast. After testing a variety of temperature/time profiles, they may have produced some successfully roasted beans to continue processing.

The husks must be removed from the roasted nibs. The husks can be loosened from the beans by cracking the husks by hand or by grinding the beans coarsely. Our students were given the option of using a coffee grinder, a mini-food grinder, or their hands for cracking the husks. Once the husks are cracked from the nibs, they must be separated from the nibs. Since the husks are papery and the nibs are dense and oily, the husks can be removed by blowing them with a hair dryer set on cool. After the husks are removed, the roasted nibs are ready to be ground into chocolate liquor or mass.

Properly grinding the nibs into liquor requires a Champion Juicer[7], which costs more than $200. The students can do a decent job less expensively by first using a mini-food grinder or coffee grinder and following up with a mortar and pestle. The goal of grinding is to get cocoa particles suspended in cocoa butter, so the students may be able to see cocoa butter separating as they let the liquor cool.

The students can make chocolate directly from the liquor, or they can separate the liquor into cocoa powder and cocoa butter by pressing. If they want to make white chocolate, they must separate the powder and butter because white chocolate contains no cocoa powder. Composition ranges of different kinds of chocolate are given in Table 1. The ingredients may be mixed with the liquor using the mini-food processor, with heating in a microwave if necessary.

Table 1. Compositions of different types of chocolate, by mass.

Ingredient/Chocolate Type	White	Milk	Dark (Semisweet)
Cocoa Liquor	none	≥ 10%	≥ 35%
Cocoa Butter	≥ 20%	allowed	allowed
Sugar	≤ 55%	allowed	allowed
Milk Solids	≥ 14%	≥ 12%	≤ 12%
Flavorings	allowed	allowed	allowed
References[4]	21 CFR 163.124	21 CFR 163.130	21 CFR 163.123

Chocolates can be made from the liquor, but the products will be grainy. To make commercial quality chocolates, the liquor and other ingredients must be refined to reduce the particle size to 20 – 30 microns and conched or kneaded to develop flavor. The refining step can be done in a tabletop wet grinder[7], which is also more than $200. Some conching also occurs in the wet grinder. After conching, the chocolate must be tempered to avoid separation of the cocoa butter from the rest of the ingredients. Tempering is gentle heating and cooling to crystallize the cocoa butter. After tempering, the finished chocolate is poured into molds or used to coat crème centers or cookies. Refining in the wet grinder takes several hours, so we recommend that the freshmen students skip the refining, conching, and tempering steps.

Students might appreciate having other supplies in case of processing failures. Internet vendors can also supply roasted nibs and cocoa butter. Small, inexpensive samples of milk and dark chocolates are available in grocery stores (Hershey's Kisses).

Equipment and supplies expenses are listed in Table 2. Many items can be borrowed from faculty or student kitchens to reduce costs. Remember to use equipment dedicated to food use – do not borrow from the chemistry stockroom!

Table 2. Estimated costs for equipment and supplies

Category	Item	Cost per item
Equipment	Hot air popcorn popper	$25
	Hair dryer (cool setting required)	$15
	Mini-food processor	$15
	Coffee grinder	$15
	Mortar and pestle	$20
	Microwave oven	$30
	Champion Juicer	$260
	Santha wet grinder	$265
Supplies	Milk, 1 quart	
	Sugar, 4 lb bag	
	Cocoa butter, 1 lb	$10
	Fermented cocoa beans, 1 lb	$20
	Roasted cocoa beans, 1 lb	$20
	Various plates, napkins, spoons	$10
	Chocolate molds	$3 to $5

Extensions of the Project

Freshmen attempt chocolate making during the fall semester, and they have the opportunity to share what they have learned with middle school students during our National Engineer's Week Open House. The chemical engineering display has a poster with the cocoa processing flowchart and pictures of the cocoa in different stages of processing. Small cups of the cocoa in different stages and our processing equipment are also available for inspection. The different chocolate processing steps and their similarity to chemical engineering processes are discussed. The compositions of the different chocolate types are described, and the middle schools students can choose to sample either milk or dark chocolate. With this display we hope to tie chemical engineering to something they are fond of.

As sophomores the students learn mass and energy balances in ChE 2003: Principles of Chemical Engineering. In 2002, a team from Rowan University presented a paper entitled "Guilt-free Chocolate" at the AIChE fall meeting[8]. These concepts have been adapted at The University of Tulsa. The first week of the course the students carefully make chocolate covered Oreos. They are encouraged to minimize waste and create a consistent product. Their homework is to create a nutrition facts label for their product (see Figure 2). They also must do statistical analysis of their product and compare it to the commercially-available Chocolate-Covered Oreo. This enables the students to develop their own method for doing a mass and energy balance before they have been taught a formal approach in class. The students also learn for themselves the concepts of recycle and waste. The students have a good time in this hands-on introduction to the course.

Nutrition Facts

Serving Size 1 cookie (23 g)

Calories 120

Calories from Fat 58

Amount/serving	% Daily Value
Total Fat 7 g	10%
Saturated Fat 4 g	20%
Cholesterol 0 mg	0%
Sodium 68 mg	3%
Total Carbohydrates 16 g	5%
Dietary Fiber 1 g	3%
Sugars 11 g	
Protein 1 g	

Figure 2. Nutrition fact label from student-produced chocolate-covered Oreos.

Conclusion

Students enthusiastically embrace these edible experiments and the entire college looks forward to eating the resulting products once each year. A recent transfer student said "I missed the intro class of 'fun things chemical engineers do', so getting to explore real life problems on a small scale with projects that kept my interest was perfect. My best memory was the project day of weighing Oreos and chocolate, melting the chocolate and covering the

cookies. Not only did we learn about chocolate messes and how unhealthy chocolate covered Oreos are for us, but also about chemical processes, mass balances and using Excel to make tables and graphs." Last year when students needed to raise funds for a trip to Scotland, they produced chocolate-covered Oreos and sold these across campus. They also created chocolate-covered coffee beans by roasting green coffee beans and coating them in chocolate. Campus-wide the chemical engineers are known for having the best tasting classes. As one student said, "Playing with chocolate in class was sweet! It was a delicious way to learn about mass balances and have fun with my classmates."

References

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