Chemical Engineering and Cosmetics: Making the Connection Between Chemistry and Engineering Processes in Product Manufacturing

Rosemary Frollini, Annette M. Jacobson
Carnegie Mellon University

Abstract--This workshop will provide an activity for middle school and high school educators and those involved in outreach projects to assist them in promoting engineering and science careers to youth. It will also provide an opportunity to bring industrial technology into the classroom using cosmetic and personal care products as a focus. Workshop participants will explore the processes involved in the manufacture of soap and the role of the chemical engineer. Each participant will manufacture their own personal care product. Using process symbols for chemical engineering unit operations, they will design a process flow sheet that accurately describes the steps taken to make their product. In any product, each ingredient has its own essential function in the product formulation. Ingredients determine the properties and effectiveness of the final product. A discussion of the ingredients in a sampling of popular consumer products will lead to the final activity, product testing. Product testing is a necessary and important part of product manufacturing. Specifically, we will consider product testing with regards to ingredients with a function important to skin care, pH adjusters. Participants will develop an awareness of the part played by the engineer and scientist in the formulation and processing of products that they use everyday.

Chemical engineers use science and mathematics to transform materials in nature into an amazing variety of products that we use every day. These products include cosmetics, medicine, clothing, food and toys, just to name a few. The chemical engineer develops a PROCESS which describes how you take the materials (chemicals) and combine them to form a PRODUCT. A PROCESS is an orderly description of each task that must be accomplished to make the product. You can think of following a recipe to make a cake as an example of a process. If you do not follow the directions properly, you will not get the best looking or best tasting cake.

The proper chemistry required to make a product is essential. It is here that scientists and engineers work together. Chemists provide the chemistry needed to make a product. The engineer takes the chemical recipe and forms it into a series of steps (the process) defined by equipment needed to perform each step. The chemistry defines the order of each step in the process and the engineer uses mathematics to determine how much product can be made, the quantity of initial ingredients needed and how fast the product can be made. This is of course very important, since a company wants to make a product that is affordable for people, as well as profitable.

In this paper we present an activity suitable for middle and high school students. The student makes a cosmetic product that they can keep. Once they have experienced the steps involved in making the product, they are able to construct the process diagram necessary to describe the manufacture of the product. This exercise gives the student a first hand look at the important role of chemical engineers in making useful products for society.

The Chemical Manufacturing Process

In the production of cosmetics and personal care products, the highest standard of quality control must be followed to assure the manufacture of safe products of uniform quality. It is the job of the chemical engineer to design and oversee the manufacturing process.

All of the steps in the process must be determined including temperature control, mixing speed, addition of ingredients, etc. These "process requirements" are essential to the quality of the finished product.

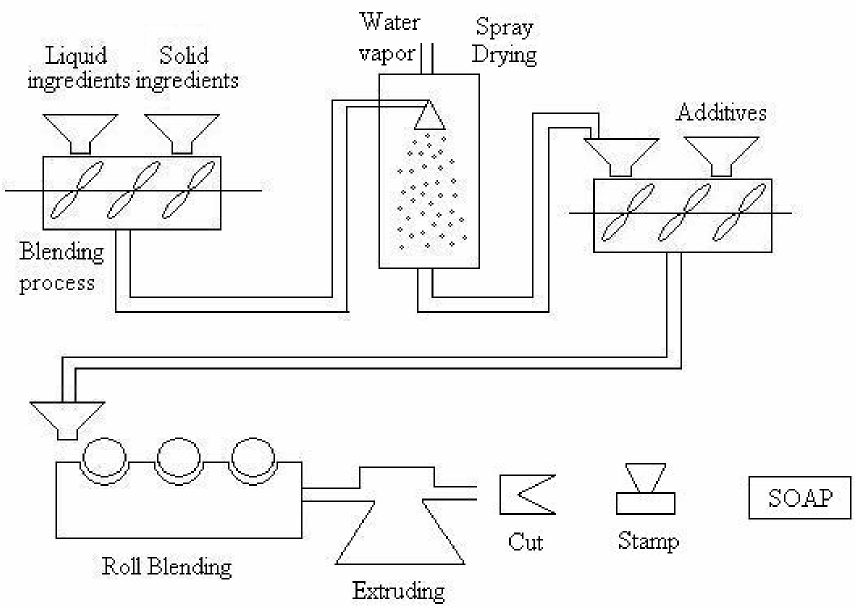

Figure 1: Process for the Manufacture of Soap
(A Process Flow Diagram)

For example, consider a process for making a bar of soap shown in Figure 1 (The Soaps and Detergents, 2005). Liquid and solid ingredients are combined in a large tank and mixed into a thick suspension called a slurry. The slurry is pumped to a tower, and atomized through small nozzles under pressure to produce small drops which fall through a current of hot air, drying them into small granules or pellets. The pellets pass to a finishing line where they are blended with additional ingredients (additives) such as fragrances and colorants.

The mixture is sent through rollers for blending to a uniform texture. It is then extruded, cut into bars and stamped into its final shape.

Each step in the process is called a unit operation. Mixing, separating, drying, cutting, heating and cooling are examples unit operations. These can be illustrated by words and symbols. Figure 2 shows some symbols which can be used to define (or illustrate) the unit operations of making a cosmetic product. As shown for the soap making process, the symbols are organized together to form the process.

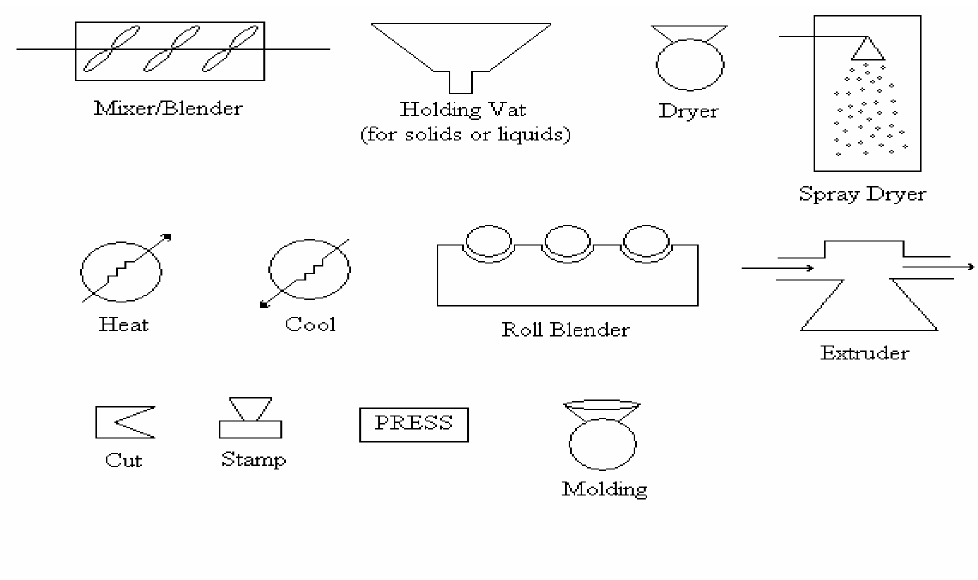

Figure 2: Process Symbols for Unit Operations

A more general way of looking at a process is to develop a simple block diagram from a description of the process. Block flow diagrams are illustrated as a set of connected blocks, or process units. Lines with arrows connect the blocks and indicate the direction of the process flow or "stream". Raw materials always enter (as input) on the left and products leave (as output) on the right.

Only four kinds of process units are used in block flow diagrams; mixers, reactors, separators, and splitters. **Mixers** combine two or more materials (inputs). One or more chemical reactions take place inside a **reactor**. An input stream is separated into two or more outputs by a **separator**. The outputs from a separator have different chemical compositions from each other and from the input. The change in chemical composition is due to physical operations, not a chemical reaction. A **splitter** also separates an input into two of more outputs but now the outputs have the same chemical composition. (Murphy, 2007)

A block flow diagram for the soap manufacturing process is given in Figure 3.

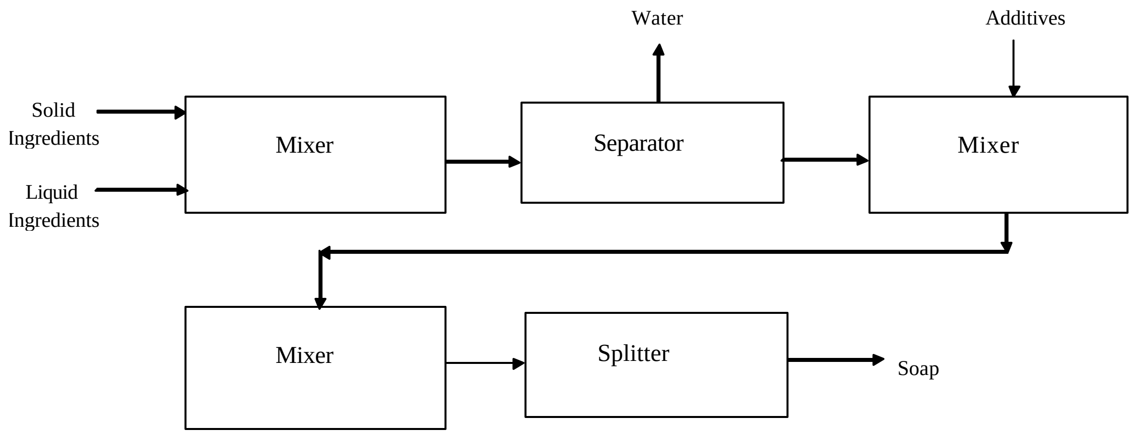

Figure 3: Block Flow Diagram for Soap Manufacturing

The first part of the activity involves the manufacture of a personal care product. BATH FIZZIES "fizz" when placed in water because of a reaction between two of the ingredients, sodium bicarbonate (baking soda) and citric acid. When in contact with water, they react to form carbon dioxide gas – the fizz – just like the tiny bubbles you see when you open a bottle of soda.

Directions for Bath Fizzie Manufacture

- Mix the following ingredients together in a bowl:
  ½ cup baking soda, ¼ cup citric acid, ¼ cup Epsom salt.
  Measure carefully. Be careful not to get any moisture (water) into the dry ingredients or they will begin to react.
- When the dry ingredients are well mixed, add ½ tablespoon of baby oil. Measure carefully. When everything is well mixed, add an additional ½ tablespoon of baby oil. Mix again. The mixture will seem dry.
- Press a small amount into both sides of a mold, being careful not to get any in the tracts where the mold snaps together. If you do, use a toothpick to clean it out. Put the mold together. If using a one piece mold, fill as directed.
- Place a rubber band on the mold to hold it together if needed. Let the BATH FIZZIE remain in the mold for 24-48 hours, then remove and toss into a bath tub full of water. Be careful as even the small amount of baby oil in your BATH FIZZIE may cause the tub to become slippery!

Bath Fizzie Flow Diagrams

After manufacture, it is now possible to prepare a block flow diagram for the manufacturing process of the bath fizzie product. In addition, students can use unit operations symbols to draw a process flow diagram. This activity demonstrates how one takes a written description of directions, and translates it into a process diagram. Once the process diagram is created the engineer knows what kinds of equipment are needed. It is now possible to perform mathematical calculations around each piece of equipment to determine the quantity of input materials you need for a specific output of product.

The Chemistry of Cosmetics and Personal Care Products

Ingredient selection is an important step in the manufacturing process, because the ingredients determine the properties and effectiveness of the final product. The next part of the activity involves a discussion of the ingredients found in common cosmetics and personal care products (Antczak & Antczak, 2001). After pointing out that ingredients are listed in order of the amount present in the product (with the one present in the largest amount first), it is important to note that the exceptions are ingredients acting as medications. Then, this “active” ingredient is listed first.

Each ingredient has its own specific function. Common terms used in describing these functions are then discussed. A few examples are antioxidant, binding agent, emollient, foaming agent, humectant, preservative, surfactant, pH adjuster, UV absorber and viscosity adjuster. Lists of ingredients and their functions can be found at the websites referenced (“Botanicals”, 2005; USFDA, 2005). Students are then asked to identify the function of the ingredients in a few products.

In examining the ingredients in lipstick, they may find that it contains bentonite clay to control thickness, lanolin, a moisturizer, oxybenzone, a UV absorber and mica, a mineral which adds sparkle. Other products that can be examined are eyeliner, foaming bath grains, toothpaste, deodorant sticks, gel skin cleanser, and hand cream. The final product that can be examined is the bath fizzie that was just made.

The Importance of pH

As each product is studied, it will be noted that many contain pH adjusters. So why is this an important ingredient? pH is a chemical term used as a measure of acidity. pH ranges from 1 (very acidic) to 14 (very basic). A pH of 1-6 is acidic, 8-14 basic and a pH of 7 is considered to be neutral.

The human skin and hair have a pH between 5 and 6, which means that they are slightly acidic. This is due to a complex mixture of natural chemicals covering the skin that have the ability to neutralize bases. This acidic environment helps to prevent the growth of bacteria and also protects against substances with a high pH. It has been shown that soaps and cleansers of high pH (basic) can be very irritating to the skin (“How Does the pH”, 2006; “Skin Care”, 2006) and can temporarily remove this acid barrier. This is why shampoos, lotions, creams, and most soaps have a pH adjusted to the pH of the skin, 5-6. In general, products with pHs above 8 may be irritating to the skin.

In the final part of the activity, products including household cleaners are tested using broad range pH paper to determine the pH and predict which ones may be irritating to the skin.

Included for testing are shampoo, lotion, astringent, gel hand cleaner, laundry detergent and liquid household cleaner.

Practical Information for Presenters

Acting as an effective presenter requires both organization and knowledge of the target audience. Advanced planning is always required in order to have the needed supplies on hand and to anticipate any problems. The activities presented here can be easily adapted to any age group.

We suggest that all of the activities be done in groups of 2-4 students. Equipment can then be shared along with the experience! The "recipe" for the bath fizzies makes 1 cup of product so the number of "fizzies" depends on the size of the mold used. In general, unless the group is very small, a small mold is best to use in order to keep the amount of supplies needed manageable. Some suggestions include plastic containers used for fruit or pudding cups, candy molds, plastic eggs, or tea strainer balls.

The chemicals used in the Bath Fizzie activity are all available to the general public. Baking soda, Epsom salts and baby oil can be purchased in a grocery store. (It is usually necessary to process the Epsom salts in a coffee grinder so that it is more finely ground.) Citric acid is used in baking, wine and cheese making, as well as in soap making and can be purchased from local stores and web sites specializing in these activities.

Other types of oils can be used as the binder, but baby oil was chosen because of its low cost, pleasant scent, and low probability of allergic reaction. Other oils which are often used in soap and bath salts are apricot kernel oil, sweet almond oil, grape seed oil, olive oil, sunflower oil, and wheat germ oil. Even though only a small amount of baby oil is used in the bath fizzie, it is still enough to result in a slippery tub just as using bath oil does. This should always be pointed out.

Broad-range pH paper indicates pH from usually 2-12 pH units by simple color change. It can be purchased from scientific supply houses such as Fisher Scientific and Flinn Scientific. Any type of small container can be used for pH testing, but one with separate chambers of some sort will keep the liquids from spreading into each other. Artist trays are very inexpensive and easy to find at craft or art supply stores.

The above activities are easy to expand for more advanced students. For example, discuss the chemical reaction of the bath fizzie, either in terms of the chemical names or the actual chemical formula.

Citric Acid + Sodium Bicarbonate → Sodium Citrate + Carbon Dioxide + Water

$$C_6H_8O_7 + 3NaHCO_3 \rightarrow Na_3C_6H_5O_7 + 3CO_2 + 3H_2$$

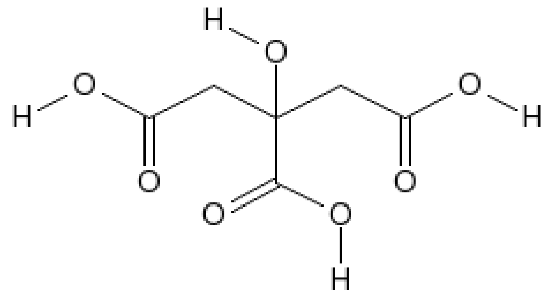

Figure 4 Chemical Structure of Citric Acid Molecule

Advanced students could draw the chemical structure of the citric acid molecule (Fig. 4). They could also discuss the substitution of the hydrogen ion on the carboxyl group of the citric acid with the sodium ion from the bicarbonate.

Mathematics is easily included by calculating the percentage of each component in the bath fizzie mixture. An additional task that could be done by all levels is preparing a product label, listing the ingredients in order of their amount in the product.

To test their understanding of the chemical engineering concepts presented in the first activity, ask the students to develop a flow chart for an activity they may be more familiar with such as baking cookies or making ice cream.

For the ingredient activities, it is useful to generate an abbreviated list of ingredient uses, with only those needed for the products you plan to examine. Use of long lists is often very time-consuming and sometimes frustrating for students. Students may determine the ingredient functions in one of their own cosmetic or personal care products by using internet search engines to find any ingredient that may not be on the list provided.

The final part, pH testing provides an opportunity for discussions of acids and bases in the household in general. Very young students can understand the concept of pH in terms of a simple number line with the numbers 1 to 6 being acids, 7 being neutral, and 8 to 14 being bases.

These activities align well with the National Science Standards and are easily incorporated into the curriculum. They have been presented to teachers and high school girls through a variety of summer programs. Here are some representative comments from participants of the Cosmetics Workshop. Teachers felt that the activity had real world applications and that students would pay more attention to the ingredients in a product when making purchases because of the heightened awareness that this activity provided. Students had comments that included "liked to see how products are made", "liked hands-on and make and take activities", and "enjoyed discovering why certain ingredients are in there". They also wanted to add more ingredients like color and fragrance to their product and wanted to spend additional time on the activity.

Besides bath fizzies, other products that are easily manufactured by the student are lip gloss, hand lotion and liquid hand soap ("Bath and Beauty", 2006; "How to", 2006; "Homemade", 2006; “Adventures”, 2006; Sarquis, 1995; Sarquis, 1995). Presenters will find that they can engage audiences of all ages with these exercises because they are relevant to everyday products and will spark an interest in and an awareness of the role of the chemical engineer in the manufacturing process.

References

“Adventures in Lip Balm”. Retrieved March 24, 2006 from www.notmartha.org/tomake/lipbalm.html

Antczak, S., and Antczak, G., (2001). *Cosmetics Unmasked*, Harper Collins Publishers, London,

“Botanicals and Ingredients”. Retrieved Sept. 2005 from www.beautyandthebeat.bigstep.com/generic4.html

“Homemade Soap, Lip Gloss, and Face Masks”. Retrieved March 24, 2006 from www.kidzworld.com/site/p1897.htm

“How does the pH of Skin Serve as a Barrier Against Bacteria?”. Retrieved March 24, 2006 from www.madsci.org/post/archives/1999-04/923688996.Me.r.html

“How to Make Lip Gloss”. Retrieved March 24, 2006 from www.creativekidsathome.com/activities/activity_40.html

Murphy, R.M. (2007). *Introduction to Chemical Processes*, New York: McGraw Hill

Sarquis, M., Ed. (1995) *Dirt Alert-The Chemistry of Cleaning, Science in Our World*, Vol. 3, Middleton, Ohio: Terrific Science Press

Sarquis, M., Ed. (1995) *Fat Chance-The Chemistry of Lipids, Science in Our World*, Vol. 4 Middleton, Ohio: Terrific Science Press

“Skin Care – About Your Skins pH”. Retrieved March 24, 2006 from www.herballuxuries.com/skinspH.html

The Soaps and Detergents Association, “Soaps and Detergents Manufacturing”. Retrieved Sept. 2005 from http://sdahq.org/cleaning/manufact/products/ingredients1.html http://sdahq.org/cleaning/manufact/products/ingredients2.html

US Food and Drug Administration, “Chemical Ingredients Found in Cosmetics”. Retrieved Oct. 2005 from http://vm.cfsan.fda.gov/~dms/cos-chem.html

Author Contact Information

Rosemary Frollini, rf3n@andrew.cmu.edu
Annette Jacobson, jacobson@andrew.cmu.edu