

Cookies, Diapers, and Chemical Engineering

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Engineering faculty are often asked to present demonstrations as part of university open houses or as outreach to assorted K-12 groups. Although it's tempting to resort to the traditional "slime" or acid-base color change demonstrations, Chemical Engineering faculty face a unique challenge and opportunity as we seek to distinguish the field of chemical engineering from chemistry. One way to do this is to emphasize the "process" and "product" nature of the field.

This paper spotlights two demonstrations, each of which focuses on consumer products that are familiar to every participant: cookies and diapers. In the "cookie" demonstration, participants gain hands-on experience in production, product/process variability, quality control, supply chain management, process economics, and process control by making cookies and analyzing the process. The "diaper" demonstration compares the performance of two related products: traditional super-absorbent diapers and swim diapers. Participants perform simple tests to see how much fresh water versus saline is absorbed by the two types of diapers and discuss the impact of materials of construction and product design. Both of these demonstrations are inexpensive, utilize easy-to-obtain materials, and can be adapted for groups ranging from K-12, as well as college students and the general public. Most importantly, they focus on the unique process and product attributes of chemical engineering, helping participants make the connection between the products they use every day and the chemical engineering behind them.

These demonstrations were developed and implemented at North Carolina State University by the author between 2000-2002 as part of SITE (Student Introduction To Engineering), a week-long program for high school sophomores, juniors, and seniors sponsored by the College of Engineering. The demonstrations have also been implemented in the week-long Alcoa Summer Engineering Academy at Centennial Middle School in Raleigh, NC for middle school students, as well as the day-long Expanding Your Horizons conference at North Carolina State University for seventh grade girls.

COOKIE DEMONSTRATION

Prior To The Demo:

- Identify the location of the baking project. Ideally the location will have an oven, a sink, and a refrigerator available. I have used the faculty lounge in our building, a staff lounge in a nearby on-campus building, and the home economics room in a middle school. If such a location is not available, or if time does not allow, consider doing a "virtual" demo, having all the ingredients and equipment available, and talking the group through the cookie making process.

- Purchase or acquire the materials for the demonstration. I have two complete sets of equipment in Rubbermaid containers that can easily be transported for demonstrations. Cost of the demo materials is shown below (2002 dollars).

CAPITAL COST	Unit Price
2 Cookie Sheets	\$12.00
Storage Box for Equipment Storage	\$4.00
Mixing Bowl Set	\$9.99
Spatula	\$2.99
Cookie Scoop	\$2.00
Whisk	\$0.99
Measuring Spoons	\$2.49
Long Handled Spoon Set	\$2.49
Detergent	\$1.49
2 Pot Holders	\$1.99
Roll of Paper Towels	\$1.29
Measuring Cup Set	\$1.99
Total	\$43.71
OPERATING COST	Unit Price
Flour (5 lb bag)	\$1.99
Baking Soda (1 box)	\$0.59
Salt (1 carton)	\$0.44
Butter (4 sticks)	\$2.89
Sugar (5 bag)	\$1.99
Brown Sugar (2 lb bag)	\$1.29
Vanilla (1 bottle)	\$1.99
Eggs (half dozen)	\$0.65
Chocolate Chips (1 bag)	\$1.99
Total	\$13.82

Initial Discussion Questions/Topics:

What is a process?

- It can range anywhere from baking cookies to a large-scale manufacturing plant.

How big is a process?

- Usually you start small – go from a tabletop experiment to a pilot plant to a large-scale operation. Typically computer simulation occurs between the lab experiment and the pilot plant. This makes it a whole lot easier to clean up a mess made by an explosion!

What are sources of process variability?

- Different raw materials
- Variable conditions
- Different operators
- Human Error
- Mechanical Failure
- Weather Conditions
- Equipment Calibration

How do you judge quality?

- Appearance
- Performance on certain tests
- Taste
- Size
- Purity
- Physical Properties
- Does it serve its purpose?

What types of things do you measure in a process?

- Temperature, pressure
- Movement of material
- Mixing times
- Output (yield)
- Quality of the product

The Assignment:

Specifications: With the given ingredients, produce as many cookies as possible that are:

- Soft
- 3 inches in diameter (+/- 1/2")
- Consistent in appearance
- Not burned

Instructions: Make a HALF BATCH based on the recipe below:

ORIGINAL NESTLE® TOLL HOUSE® COOKIES

Ingredients

2 ¼ c. unsifted flour
1 t. baking soda
1 t. salt
1 c. soft butter
¾ c. sugar
¾ c. firmly packed brown sugar
1 t. vanilla
2 eggs
1 12 oz pkg. Nestle® Semi-sweet Chocolate chips

Directions:

Preheat oven to 375°F.
In small bowl, combine flour, baking soda, and salt.
In large bowl, combine butter, sugar, brown sugar, and vanilla.
Beat until creamy.
Beat in eggs.
Gradually add flour mixture. Mix well.
Stir in chocolate chips.
Drop by rounded measuring teaspoonful onto ungreased cookie sheet.
Cook 8-10 minutes or until brown.

Show each group where their work area is and give them time to get organized. Have someone available to help but allow the group to develop their own process (and make their own mistakes). Typically an hour is sufficient time for the group to get organized, make a half batch of cookies, and clean up. If you have more time, they can make several batches and measure the variability between batches, try different approaches, vary key parameters in the process, etc.

When the groups recombine, let each group give a summary of their baking experience (and share the results, of course!) Allow them to tell about mistakes made or things that they saw that they could be changed to improve the process.

Discussion questions to pose to the group after they have completed the assignment:

- How much does each cookie cost?
 - You must consider both capital cost (mixing bowls, spoons, hot pads, cookie sheets, measuring cups, measuring spoons, etc.) and operating cost (flour, sugar, vanilla, eggs, etc.) How would the cost per cookie decrease as you make more cookies?

- What's the difference in buying "name brand" versus "generic" products? In cost? In quality?
- How would you cut costs and scale-up the production?
- How much waste does the process generate?
- How would you reduce waste?
- What variability exists in the process (i.e. what can change to affect the resulting product)?
- What are the characteristics of a "good" product?
- What variables should we monitor for this process?
- How did you divide up the work?
- How could we make this more efficient (faster, cheaper)?
- How could we make a better product?
- What different products could be made based on this idea? How can we best position this product to maximize sales?
- How would we scale this up to make 1000 batches per day?

Observations/Conclusions:

- Every product is made using a process.
- Quality control is essential to get a "good" product.
- Processes can always be improved, whether that means increasing the yield, cutting the cost, reducing waste, or improving the quality of the final product.
- Chemical engineers are trained to be "process engineers," whatever the process.

DIAPER DEMONSTRATION

Prior To The Demo:

Purchase or acquire the following items. Assuming that participants work in teams of two, you will need three superabsorbent diapers and three swimpants for each team.

- Regular Huggies [®] superabsorbent diapers (approximate cost = \$10 for a package of 56 diapers, Size 1)
- Huggies [®] Little Swimmer Swimpants (approximate cost = \$10 for a package of 10 diapers). Note, these may be hard to find in the winter as they are a seasonal product.
- Disposable aluminum roasting pans to use as "dissection pans" (\$3.99 each)
- Salt for making saline solution (\$0.45)
- Yellow food coloring (\$3.49)
- Scissors (one for each pair of participants)
- Bucket for mixing saline solution
- Large graduated cylinders (500 ml or 1000 ml is good) –I usually borrow some plastic cylinders from the unit operations lab or the Chemistry Department.

Part I: DIAPER DISSECTION (refer to Demo Worksheet I)

Directions: Examine each diaper carefully on the outside and note any differences or distinguishing characteristics. Cut the diaper down the vertical seam to reveal the lining material, examine the inside of the diapers carefully, and note any differences or distinguishing characteristics.

Following are notes that you may want to use as a basis for discussion, depending on the age and background of the participants:

Regular Huggies ® superabsorbent diaper:

- Compact, thin
- Outer cover of diaper is spun bond fabric laminated to a breathable film – feels like fabric, not plastic – plastic is underneath – plastic is designed to let air to pass through – breathable.
- Open product – designed to lay out flat so that with an infant, you can lay it underneath and wrap around
- Hook and loop velcro closures
 - Color graphics on front panel represents the target zone that is mated to velcro hooks
 - Circular raised bond pattern on graphic pattern – this is high bulk, spun bond polypropylene filaments – specifically designed to hold on to the velcro hook – want the hook to be completely engaged so that the skin won't encounter an abrasive surface.
 - Velcro receiver panel goes across whole front of diaper so that there is flexibility in sizing.
 - Note that some competitor products use tape, but most premium diapers are mechanically fastened (not tape).
- Note stretch fabric in panel closure to give comfort stretch – non-woven laminate engineered for this purpose.
- Boy versus girl diapers:
 - Boy diapers have blue containment flaps. The position of the absorbent panel is shifted slightly to front, higher up on front pane.
 - Girl diapers have pink containment flaps. The position of the absorbent panel is more toward crotch
 - Target of absorbent panel is “point of insult”.
- Containment flaps – stand up because there are two strands of elastic – designed to hold in runny BM and excess urine that takes awhile to get absorbed.
 - Can be a film fabric composite or spun-bond melt blown material (similar to surgical wrap).
 - Containment flaps work together with leg elastics embedded in white edges to help give good leg fit and limit leakage.
- Top inner surface of diaper – spun bond polypropylene designed to be soft and allow rapid penetration of urine into absorbent underneath.
- Second inner layer is bulky non-woven used to accommodate large insults – “surge” material – low density material construction that provides some place for liquid to go with little resistance - allows liquid to penetrate and spread. Liner and surge work with absorbent to

keep liquid away from skin – the diaper’s purpose is to keep baby’s skin dry and stop leakage.

- Inside layer is a combination of fluff pulp and superabsorbent (a high molecular weight sodium salt neutralized polyacrylic acid, usually in a granular form). The inside layer is a blend of fluff pulp and superabsorbent.
 - Absorbent is there to contain the urine.
 - “Plain” pulp fibers have a retention value of 7 g/g (each gram of pulp fiber can contain 7 g of urine).
 - “Superabsorbent” has capacity of 30 g/g urine.
 - Note that early diapers were totally fluff pulp – they were competing with cloth diapers (roughly the same 7 g/g) – but disposable diapers with superabsorbents are a dryer product than cloth diapers that stayed wet against the skin.
 - Other applications of superabsorbent: superabsorbents are also used in agriculture to help hold water in arid areas – incorporated in the soil – holds onto liquid to prevent it running off – as the surrounding ground dries, the absorbent releases the liquid. Gardeners may include superabsorbent pellets in potting soil.
- Total absorptive capacity for a small diaper: 400 ml of urine (water is 3-10 times that)
 - Why the difference? The ionic content in urine decreases the absorbent capacity of the polyacrylate superabsorbent (sodium in urine is excluded from the interior of the superabsorbent particle) – water diffuses in, sodium ion stays on the outside. If no ions, absorption is limited only by crosslink structure.
 - Composition of urine: close to 0.9 wt% NaCl, some ureic acid and some low levels of protein, some divalent and trivalent ions.
 - Other examples of diffusion:
 - When you put living animal cells in pure distilled water, they will absorb excess water and may explode. They are used to being in 0.9% saline solution in the body. When they are put in pure water, they absorb water until the cell explodes.
 - Hydration for high performing athletes – conventional wisdom is that you should drink water when exercising to replace water. Extreme exercise (high intensity, more than an hour) – not only lose water, but sodium. The body can accommodate loss of water and sodium, but if it loses too much and you replace only with water, you get a condition which is similar to water intoxication – such low sodium levels, as you take in water you begin to become disoriented because the brain isn’t functioning at normal levels. The cells are getting too much water, and electrical impulses that are facilitated by that ion level are not as efficient. There have been deaths due to drinking too much water during and after hard exercise. Sports drinks (Gatorade) are increasingly recommended for people that exercise for more than an hour at a high intensity to balance hydration and maintain ion content.
- Diapers are designed to absorb 400 ml of urine – but in a swimming pool there is nowhere near the ionic content of 0.9% saline, so the diaper just keeps absorbing water with nothing to impede the absorption -- 1000 or more ml of water. A superabsorbent diaper just keeps

pulling water in until it reaches the design capacity of crosslink density. This swelling pressure may cause the diaper to burst.

Little Swimmer ® Swimpant:

- People often put children in the pool with their regular superabsorbent diaper.
 - Uncomfortable for child
 - Swelling of superabsorbent exerts a strong force that it would split the diaper open and empty contents
 - Goal was to provide a product that did not have the problems with excessive water absorption but provided enough absorbent protection for 1 insult (40-60 ml of urine), and was durable and comfortable enough that the child felt free to enjoy the water.
- Thinner, more compact than regular diapers.
- Give protection before water play, but also increase water play enjoyment
- “Closed” pant design – designed to be like a swim trunk
- Side panel stretches – can pull over the hips and fit snugly on the hips and waist
- Outer cover is very durable – child can scoot on his or her rear, won’t rip easily
- Colored and printed to make it look like a bathing suit – emphasize fun aspect
- Outer surface is SMS (spun bond melt blown)
- Green piece along the waist line – improved waist elastic for better fit and containment. White containment flaps provide better gasketing along legs to help hold in solids
- Top layer is spun bond polypropylene – same as regular diaper.
- Absorbent is a coform absorbent composite – no superabsorbent present. Coform is fluff pulp held together by melt-blown polypropylene fibers –it has good dry and wet integrity – keeps its shape, doesn’t swell out like regular diaper – maintains fit of diaper when it’s wet, but doesn’t swell -- holds about 90 ml water or urine – since no superabsorbent, no differential between absorption for water and urine.
- Swim pant designed to hold only one accidental insult from the time the pant is put on until they reach the pool (avg. 30 min).
- Product will weigh at most 90g more when wet – doesn’t absorb extra water and become uncomfortable – more durable.
- Other features: side panels are ultrasonically bonded so that they can be torn apart in case of BM accident.

Part II: PERFORMANCE TESTING (refer to Demo Worksheet II)

Instruct the participants to use the roasting pans as a work surface for this part to minimize mess. First for the superabsorbent diaper and then the swimpants, **slowly** pour tap water and let absorb. You may get some “run-off”, but continue to pour as long as the diaper will absorb. Another approach is to dunk the diaper in a bucket to gauge total absorption, but gradual pouring is more fun for the participants. Participants should record the amount absorbed on the worksheet.

- The regular diaper should hold more than 1000 ml of tap water and will start swelling in a local area with the first 100 ml.
- The Little Swimmer should hold less than 100 ml but does not swell.

Cut open the diapers when saturated and observe the contents – the superabsorbent turns to a gel-like substance when saturated.

Repeat with saline (0.9 wt% NaCl). (Typically add 9 g salt for 1000 ml water). I add **yellow food coloring** to simulate urine (always good for the “gross out” effect for K-12 students)

- The regular diaper will hold much less of the saline solution compared to tap water – around 400 ml.
- The Little Swimmer should hold less than 100 ml.

DIAPER DISSECTION WORKSHEET (PART I)

Directions: Examine each diaper carefully on the outside and note any differences or distinguishing characteristics. Cut the diaper to reveal the lining material, examine the inside of the diapers carefully, and note any differences or distinguishing characteristics.

**Regular HUGGIES®
Superabsorbent Diaper**

Outside:

Inside:

**LITTLE SWIMMERS®
Swimpants**

Outside:

Inside:

DIAPER PERFORMANCE WORKSHEET (PART II)

Supplies:

- Two Regular HUGGIES® Superabsorbent Diapers
- Two LITTLE SWIMMERS® Swimpants
- Water (tap water is fine)
- Saline solution (0.9% NaCl) with yellow food coloring

Directions:

1. Slowly pour **tap water** into the regular HUGGIES® superabsorbent diaper and see how much the diaper will absorb. Repeat with the LITTLE SWIMMERS® Swimpants.
2. With the second set of products, slowly pour **saline** into the regular HUGGIES® superabsorbent diaper and see how much the diaper will absorb. Repeat with the LITTLE SWIMMERS® Swimpants.
3. After completing (1) and (2), think about what's going on and why each product performs as it does.

Regular HUGGIES® Superabsorbent Diaper

Maximum amount of tap water:

_____ ml

Maximum amount of saline:

_____ ml

What's going on?

HUGGIES® LITTLE SWIMMERS® Swimpant

Maximum amount of tap water:

_____ ml

Maximum amount of saline:

_____ ml

What's going on?

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