MODERNIST CUISINE
as an Introduction to Chemical Engineering

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Chemical engineering is a challenging field to explain to first-year students. Food production processes are a safe and accessible way to introduce the students to basic engineering concepts.[1] The same chemical principles that apply to an oil refinery are used to produce pasta and peanut butter. Production involves mixing complex organic molecules in non-Newtonian flow with a lot of chemistry involved. Food production processes involve heat and mass transfer, reaction kinetics and thermodynamics. Ovens need to be designed and pumps need to be sized. Chemical engineers learn the skills to design, troubleshoot and improve these processes. Modernist cuisine – using scientific methods and engineering techniques to enhance classical cooking – was used as a hook to capture the attention of first-year engineering students and introduce them to chemical engineering. Some modernist techniques improve a traditional food. For example, sous vide (a vacuum-packed food immersed in a constant temperature water bath) will cook a steak to perfection. Other modernist techniques create a novelty: add maltodextrin to peanut butter to create a powder that melts in your mouth releasing concentrated flavor. Using the science and engineering to create modernist cuisine novelties in the classroom is an exciting way to introduce students to chemical engineering.

COURSE DETAILS

All first-year engineering students at Lafayette College enroll in the Introduction to Engineering course. The current version of the course is centered on the engineering design process. The course is offered in the fall semester, and each engineering department in the division offers 7-week modules to introduce the students to the design process within their major, but not specific major content. Each first-year student enrolls in two of the modules. The class meets for 75 minutes three times a week in a standard classroom. During each module, the students also meet twice with the graphics instructor, leaving 19 class meetings for the module.

The module described in this paper, called Films, Foams and Spheres, introduces students to novel ways of manipulating foods to create modernist cuisine – that is, using scientific methods and engineering principles to improve and enrich the way food is prepared. These modernist processes are built from unit operations – and students learn that their design is based on engineering principles. The organization of the operations in an efficient manner that is environmentally friendly and ethically sound presents an example of process design. The students practice choosing and sequencing processes to create a desired food product through physical and chemical transformation of the raw materials.

ACTIVITIES

The Films, Foams and Spheres module includes at least one hands-on activity for each topic, and usually one during each class meeting. Table 1 includes a list of the activities, many of which include design assignments. Four of the activities included in three of the topics will be described in this paper, along with student responses to them. The complete set of student handout pages, instructor notes and references, activity instructions, and homework problems with solutions are available from the author (PiergioP@lafayette.edu).

Because the activities take place in a classroom (not a lab) and handwashing sinks are nearby, students are given the option – never a requirement – to taste their creations. On the first day of class, students fill out an information form where they can list allergies. Because the in-class projects primarily use bananas, milk and starches, avoiding allergens has not been a problem.

TOPIC: WATER ACTIVITY AND DEHYDRATION

Dehydration was included as a topic to introduce students to material balances, the concept of composition on a wet and dry basis, and drying as a unit operation. Table 2 lists the

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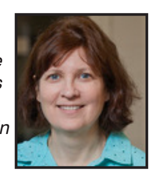

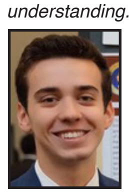

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TABLE 1 Activities for Topics in Films, Foams and Spheres. Activities in bold are described in this paper.	
Topic	**Hands-on Activities**
Introduction & Process Design	Create a process flow diagram for coffee production
Food Components	Milk component responsible for coagulation
Water Activity and Dehydration	Moisture movement (Excel), **Banana dehydration**
Starches	Properties of different starches, Effects of starch modification, **Starch gelatinization properties**, **Pumping starches**
Thin Films	Starch dehydration and film formation, Mechanical properties of films, Effects of plasticizers
Foams	Effect of process order on foam properties, Effect of process order on emulsion properties, Quantifying foam properties, Dehydrating foam
Spheres	**Creating spherical foods**, Scale-up of spherification

TABLE 2 Learning objectives for Water Activity and Dehydration	
Class	**Learning Objectives – By the end of class today, students will be able to:**
Class 1: The Science – Water activity	• Calculate moisture content on a wet and dry basis • Differentiate between moisture content and water activity • Identify the regions of a water activity isotherm • Use the water activity isotherm to predict movement of water • Calculate the water activity of a food to determine if it must be refrigerated
Class 2: The Engineering – Dehydration	• Explain why foods are dehydrated • Describe the important components of the dehydration process and equipment • Perform a material balance to find the amount of water removed from a dehydrated food
Class 3: Parameters of dehydration	• Calculate moisture content (dry basis) from mass data for bananas as they dry • Determine the water activity of dehydrated banana slices of different thicknesses • Acknowledge which parameters affect moisture content

learning objectives for the three class periods.

Example Dehydration Activity

During the third class, the students collect data while dehydrating banana slices. This required the purchase of an Excalibur 3926 9-tray electric food dehydrator with automatic temperature control for about $250 on Amazon. The dehydrator was used in two other activities in the course, as well as in a course for third year students.

The students are divided into nine groups. Each group has a half or whole banana that they cut into slices of 0.5 cm, 1.0 cm or 2.0 cm. The slices are massed as a set, placed on dehydrator trays and dried at 135 F for either 3, 5 or 24 hours at which point the set of slices is massed again. The mass data for all groups are shared with the class so students can complete the calculations individually.

Typical results are shown below in Table 3. Groups 1 – 3 sliced their bananas 0.5 cm thick, Groups 4 – 6 created 1 cm thick slices, and Groups 7 – 9 used 2 cm thick banana slices. The banana slices were weighed after 3 hours in the dehydrator for Groups 1, 4 and 7; after 5 hours for Groups 2, 5 and 8; and after 24 hours for Groups 3, 6 and 9. Outside of class, the students use the mass data to determine the moisture content of the dehydrated slices on a dry basis (assuming the bananas initially had a water content of 74% on a wet basis). By comparing the data, the students could determine how slice thickness and dehydration time affected moisture content. Finally, they use a journal article posted on the Classroom Management System to determine the water activity of the slices.[2]

From the final moisture content data the students could see how the thinly sliced bananas (Groups 1 – 3) lost more water, as did slices dehydrated for longer times. After 24 hours, however, even the thickest slices lost most of the initial water content (comparing Groups 3, 6 and 9). Because the hands-on activity took place in the classroom, and clean utensils were used, students were able to

TABLE 3
Typical results from banana dehydration

Group	Initial mass [g]	Final mass [g]	Water lost [g]	Initial water [g] *Assuming 74 % (wb)	Dry solid [g]	Final water [g]	Final moisture content [g water/g ds]	Water Activity
1	43.03	13.24	29.79	31.84	11.19	2.06	0.18	0.7
2	54.00	15.24	38.76	39.96	14.04	1.20	0.09	0.6
3	48.51	12.77	35.74	35.90	12.61	0.16	0.01	0.5
4	52.51	26.64	25.87	38.86	13.65	12.99	0.95	0.82
5	49.51	18.28	31.23	36.64	12.87	5.41	0.42	0.78
6	81.03	21.97	59.06	59.96	21.07	0.90	0.04	0.5
7	42.80	24.35	18.45	31.67	11.13	13.23	1.19	0.85
8	75.76	38.54	37.22	56.06	19.70	18.84	0.96	0.8
9	96.02	26.69	69.33	71.06	24.97	1.72	0.07	0.6

taste the bananas if they chose and note the differences in crispness at different values of water activity.

The dehydrator is used several other times during the module. The students use it to dehydrate starch films to create edible food wrappers. They also use it to dehydrate milk foam to create crunchy milk, a modernist cuisine. Finally, most student groups use the dehydrator in their final design project.

TOPIC: STARCHES

Chemical engineers use starches in a wide range of applications. For example, starch nanoparticles are biocompatible and nontoxic and important for biomedical applications and drug delivery.[3] Starch has potential as a sustainable packaging material,[4] and is used in the textile industry to stiffen fabrics and in the chemical industry to produce amino acids, surfactants and polyurethanes. Physical properties of gelatinized starch can be related to properties important to other applications in chemical engineering, such as the cloud point and pour point of biodiesel fuels. Starch is also the most common carbohydrate in the human diet and is an important ingredient for the food industry. Table 4 lists the learning objectives for the starch topic.

TABLE 4
Learning objectives for Starches

Class	Learning Objectives – By the end of class today, students will be able to:
Class 1: Chemistry and properties of starches	• Recognize the structure of starch carbohydrates: amylose and amylopectin • Illustrate what happens when hot water is added to starches from different sources • Describe two methods of starch modification • Assess how different starches mix with water
Class 2: Gelatinization	• Explain the process of gelatinization • Compare the roles of amylose and amylopectin during gelatinization • Determine the starch concentration necessary for gelatinization • Analyze how concentration and starch source affect clarity, strength and flow properties
Class 3: Physical properties of starches	• List properties measured in a texture profile analysis (TPA) • Explain how the properties are measured • Apply calculus skills to a TPA graph to estimate properties • Determine the effect of amylose concentration on starch gel color and firmness
Class 4: Pumping starches and the H-P equation	• Calculate the Reynolds number to identify laminar flow • Apply the Hagen-Poiseuille equation to pumped starch solutions in laminar flow • List three common pump types and limitations with viscous fluids

Example Starch Activity

The activity during the second class takes most of the period after a short description of gelatinization. Students are given containers with corn, potato and tapioca starch suspensions in water and twelve test tubes in an 85 C water bath. Following a dilution procedure to create four solutions from 0.01 to 0.10 g starch/mL, the starch solutions are pipetted into the test tubes. Marbles are placed on top of each tube to prevent evaporation. After 5 – 10 minutes, starch gelatinization is completed and the test tubes are placed in an ice bath for easy handling.

The students then estimate properties of the starch gels they have produced using methods that mimic industry standards. First, the clarity of each test tube is estimated using a photo of turbidity standards. Next, the gel strength is estimated by using the same force to poke a chopstick into each gel and noting the number of millimeters it inserts. Some of the gels are soft enough to flow. For those, 0.1 mL of gel is placed on a flat tray. The tray is turned to vertical and the distance the gel travels in five seconds is noted. This distance is proportional to the viscosity. Finally, the gel body is estimated by lifting a sample with the pipette and determining the strand length before it breaks.

The data are recorded on the student handout. For homework, the students choose two concentrations, scale the data and create radar graphs to compare the starches from different sources at similar concentrations and answer a series of questions. A representative graph is shown in Figure 1. Students can easily identify which starch might be appropriate for a given situation.

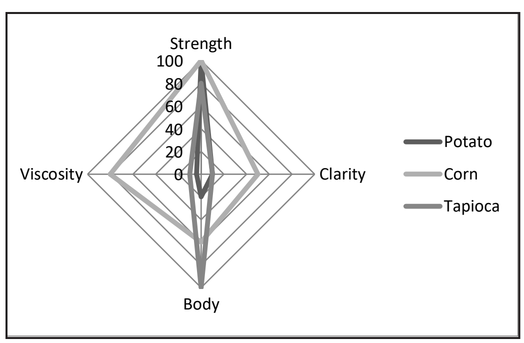

Figure 1. *Typical results for starch gelatinization at 0.04 g starch/mL water*

While developing the activity, concentrations from 0.01 to 0.16 g starch/ mL water for four starches were tested, and the four concentrations that best represented the range of behaviors were chosen for the class activity.[5] Complete details on the procedure and data for the entire range are available from the author.

Example Starches Activity

The fourth activity in this topic occurs during the last half hour of class after an introduction to the Reynolds number, laminar flow, the Hagen-Poiseuille (H-P) equation and three types of pumps. The class works together to gather data from a peristaltic pump with four heads. First, students collect data to show that all four heads move water at the same flow rate. Next, one piece of tubing remains in the beaker of water, but the other three pieces are placed in beakers filled with different viscous starch gels. The pump is turned on, and the tubing fills with the solutions. After the tubing is full, the students measure the volume of each starch gel delivered after two minutes. Students are surprised that the potato starch gel, which appears as a solid, is actually able to flow through the tubing! By the end of the activity, they have a good understanding of how a peristaltic pump works.

Outside of class, the students use the volumetric flow rates and the viscosity of water in ratios of the H-P equation to estimate the viscosity of the starches. While laminar flow was easy to observe, the students also calculated the Reynolds number to confirm. The starches are non-Newtonian fluids, so the estimated viscosity is actually an apparent viscosity at a specific shear rate. However, this was not covered in the introductory course. Students in the junior year Applied Fluid Flow course also complete the activity and estimate the power law parameters to characterize the starch viscosity.[6]

TOPIC: SPHERIFICATION

Gelation of sodium alginate with calcium chloride has applications in biomedicine and nanotechnology as well as molecular gastronomy. Labs for students to create alginate spheres and measure diffusion of a dye from them have been developed for drug delivery and similar courses.[7, 8, 9] Food spherification has been used as a demonstration in a graduate level food science and human nutrition course, but no measurements or calculations were made.[10] The goal of food spherification is to create spheres with a thin outer membrane and a liquid center. The learning objectives for this modernist cuisine topic are included in Table 5.

Example Spherification Activity

This activity takes an entire class as students make spheres from a variety of foods. Each student group is provided with about 30 mL of a 1 w% sodium alginate solution and 1 L of a 0.2 w% $CaCl_2$ solution. Many different foods (soy sauce, orange soda, hot sauce, tea, ranch dressing, peanut butter...) are available for the students to use to make spheres. Each group also has a syringe, several bowls and calipers. A cylindrical vase from the local dollar store is used for the $CaCl_2$ solution. The instructions are vague: mix a food with alginate in approximately a 3:5 ratio and drip it into the $CaCl_2$ solution using a syringe. The students discover that some foods make great spheres while other foods result in "snakes". If they taste their spheres, they can recognize that if the spheres are left in the $CaCl_2$ bath too long, the center of the sphere is no longer liquid.

The students then choose a food that made good spheres and create at least ten spheres, allowing them to harden in the $CaCl_2$ solution for 3 minutes. They use calipers to measure the diameter of ten spheres. A small aluminum bar is placed on three spheres arranged in a triangle to measure compression – the more compressible the spheres are, the more satisfying they are to eat. A noticeable sphere "pop" is especially rewarding. During the 75-minute class period, students are able to calculate the firmness – and test the "pop" – of spheres from at least two different foods. After students have made many spheres using the basic spherification process, each is given a 2 cm hemisphere of frozen strawberry milk with added calcium. The students dilute their remaining alginate solution by adding approximately the same amount of water. Then they carefully drop their frozen hemispheres into the alginate and stir for three to five minutes. Using a strainer, they remove the spheres and rinse them in a beaker of water. The consistency of these spheres resembles that of an egg yolk and the students (and instructor) are fascinated by moving them from hand to hand. A few spheres are "popped" to see the milk squirt out. One sphere is placed in the water to see it expand as water diffuses through the membrane and fills the sphere. As a homework problem, the students explain how these spheres were made – the process of reverse spherification.

Example Spherification Activity

This activity was designed to give students an opportuni-

TABLE 5
Learning objectives for spherification

Class	Learning Objectives – By the end of class today, students will be able to:
Class 1: Science and engineering of spherification	• Identify the reactants in the spherification process • Explain the chemistry of the spherification reaction • Diagram the crosslinking of the spherification reaction • List three engineering applications • Explain the difference between flow and flux • Solve simple problems using Fick's first law
Class 2: Creating spheres with foods	• Create spheres with different foods • Correctly use and read calipers to measure the sphere diameter • Use Excel to calculate the average and standard deviation of the diameter of spheres from different liquids • Measure the firmness of spheres from different liquids
Class 3: Create an abundance of spheres!	• Build a process that automatically mixes a liquid food and alginate and drops it into the $CaCl_2$ bath

ty to design a continuous sphere-producing system within a 75-minute class period. Each student group is given pumps, tubing, and connectors and asked to use the materials to continuously produce spheres of a similar size. While the project may initially seem simple, several technical and design decisions are required primarily because the food and the alginate have different viscosities. The students were pleased and proud when they successfully produced a beaker full of beautiful orange spheres!

STUDENT RESPONSE TO FILMS, FOAMS AND SPHERES

Approximately 80 students have participated in the Films, Foams and Spheres module. In addition, about 30 chemical engineering faculty participated in some of the activities at the 2017 ASEE Chemical Engineering Summer School for New Faculty. All participants – students and faculty alike – have been highly engaged in the activities, and student comments indicated they are fun. At the end of the module, student groups write a design project report that included a process flow diagram to create a new food. They have one class period to prepare and present their foods. Students created foods such as "Pinie Bites" – dehydrated pineapple with powdered caramel syrup, and "Tri-Apple D'Lite" – dehydrated apple halves filled with apple cider spheres wrapped with caramel starch films. The written reports showed an understanding of the chemistry and engineering involved in the various processes, as well as correct principles in the process flow diagrams.

The more important questions, however, are if the activities help students learn the class material and whether the module helps them learn about chemical engineering. Student course evaluations were used to assess these questions. Students used a Likert scale (from 1- 5) to answer the statement "I learned a great deal in this course" with a 5 indicating that they learned the most. The interpolated medians for two sections of the Films, Foams and Spheres module were 4.35 and 4.67. Interpolated medians for all modules taught at the same time ranged from 3.60 to 4.67 with a median of 4.14. Students believe they have learned from the Films, Foams and Spheres module.

Another free response question on the course evaluation asks students what components of the course helped them learn the material. All but three of the 80 students mentioned the hands-on activities as the primary method. For example, "the lectures did a good job of explaining the science but the projects really helped me understand what we were doing conceptually".

The final question on the evaluations asks students if they would recommend the course to others, and why. Nearly all students would recommend the course (it is required for engineering students), but the reasons indicated that the course helped students understand what chemical engineering is:

- *Excellent exposure to one potential avenue of chemical engineering. Anyone even considering chemical engineering should sign up for the class.*
- *Exciting introduction to chemical engineering with real life applications.*
- *It helped me understand what it might be like to be a chemical engineer.*
- *The course was incredibly fun and helped me feel confident in my decision to be a chemical engineer.*
- *Even though I want to be an ECE I particularly enjoyed this course quite a lot and I never liked chemistry but this course made me reconsider.*

CONCLUSION

Films, Foams and Spheres successfully introduces students to the field of chemical engineering with many hands-on activities. While constructing an introductory course around food might seem restrictive, the students were able to gain an understanding of the field of chemical engineering.

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