K-12 Demos for Outreach in Chemical Engineering

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Abstract – As part of an NSF CAREER grant, demonstrations and experiments were developed for outreach in chemical engineering. The goals of this K-12 outreach are to develop simple hands-on activities to teach high school students about particle technology, and to encourage students to consider careers in STEM fields. A further requirement is that the activities can be performed in a classroom or auditorium without the need for laboratory facilities. The purpose of using hands-on activities is to stimulate active learning. This paper discusses the implementation, including activities and discussion with the high school students. Examples of activities are given, such as simulating gold panning by dry panning. The materials needed, procedure, and experiment variations are discussed. Examples are given of discussion topics and questions that emphasize the connection of the experiments and demonstrations to real world problems as well as demonstrate scientific principles. The connection between the activities and NSF broader impacts are also discussed.

Keywords: K-12 outreach, particle technology.

INTRODUCTION

Although particle technology is vital to many sectors of the chemical process industry, the U.S. has been negligent in incorporating it into education [1, 3,4, 6, 7]. Many other countries such as England, France, the Netherlands, Switzerland, Germany, and Japan have active academic and industrial centers that focus on particle technology. Much of the emphasis on teaching particle technology in the United States has focused on college students, but not K-12 students.

Recently, there has been a focus on encouraging pre-college students to pursue careers in science, technology, engineering, and mathematics (STEM). While new STEM high schools are being opened across the nation, not everyone has the opportunity to attend a STEM school. Therefore, it is necessary to reach out to other students through programs such as summer camps. This outreach project focused on developing simple hands-on activities for use in summer engineering camps. In this paper, experiments are activities where a variable is controlled and a result is measured, and demonstrations are activities that illustrate a concept but do not have a measured result.

As part of an NSF grant, demonstrations and experiments were developed for K-12 outreach; and were used with existing high school summer camps (WISE Women Camps) co-sponsored by the Bagley College of Engineering (BCoE) and the student chapter of the Society of Women Engineers (SWE) at Mississippi State University (MSU). Selected faculty members from various engineering departments were each asked to present a 1 to 2 hour session that highlighted their discipline and department. In chemical engineering, this consisted of a presentation on the department and chemical engineering as a career, and a hands-on activity. This paper discusses two of the activities developed by the author during 2007 and 2008. For each activity, students worked in small groups of 2 or 3 students, or individually depending on the demonstration or experiment. All of the activities were related to author's research area of crystallization and particle technology.

This paper highlights a hopper flow experiment and a dry gold panning demonstration. In both cases, the scientific concept is explained to the students and an objective is given. To help the students understand the concepts, clear links are drawn with and real world applications.

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HOPPER FLOW EXPERIMENT

Preparation by Instructor

The following materials are needed for the experiment.

Hopper: cardboard and masking tape

Feed material: pinto beans (or other dried beans)

Containers for feed material: bags or jars

For each experiment, 2 cardboard sections approximately 8” x 8” are needed for the front and back of each hopper. Additionally, 2 cardboard strips approximately 8” x 2” are needed for the sides of each hopper. Therefore, it is necessary to estimate the number of hoppers needed and to purchase enough cardboard. This works well if there is a hopper for every two to three students. It usually takes at least two students to perform the experiment. Sufficient masking tape is needed to assemble the hopper. Dried beans are chosen because they are inexpensive, readily available from a grocery store, and are very regular in size and shape. Cardboard from boxes can be used as the construction material.

Before meeting with the students, it is necessary to precut the cardboard sections for the front, back and sides of the hopper. Also, it is helpful to mark the back section to indicate where the sides should be attached. It is also necessary to have approximately 1 to 2 cups of the sample feed material in a container such as a plastic jar. Each team of students will be given the cardboard sections, masking tape, and a jar of dried beans.

Instructions to Students

Experiment objective: Investigate effects of hopper opening size and hopper side angle on flow through a hopper.

Everyday application: Pouring foodstuffs (flour, sugar, or breakfast cereal) from a box or a bag

Industrial application: Common method for adding solid particles into a process

The students are told the experimental objective and the applications are presented. While the emphasis is on problems in particle technology, engineering is emphasized by focusing on the concept that the experiments can lead to better design of hoppers. The everyday application of pouring materials from a small opening in a box or bag is given to help students link the hopper application with something they already know. While one can easily shake a small box or bag when the hole becomes plugged, this is not easily done on an industrial scale. Therefore, it is essential to design hoppers well.

Students are then shown a typical hopper and are instructed to assemble the hopper in a given configuration. Specifically they are told to attach the sides to back of hopper with masking tape. They are to position the sides so that the bottom sections are at the desired angle and produce an opening of the desired size. Also the students must ensure that the bottom of the sides is even with the bottom of the back of the hopper. After this the front of the hopper is attached with masking tape. Students assemble hoppers using masking tape to hold the pieces together. A typical design is shown in Figure 1.

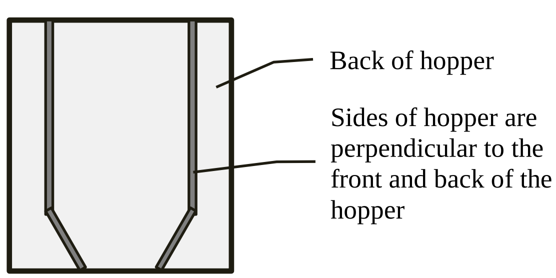

Figure 1. Schematic for hopper assembly.

Experimental Procedure

The hopper is placed on a table or desk in vertical position and the beans are added. With the bottom of hopper on desk, the beans stay in the hopper until the hopper is moved so that the hopper outlet isn’t blocked. Another alternative is to use a strip of cardboard to block the hopper outlet.

The experiment is performed by opening the hopper outlet and measure the seconds it takes for the beans to exit the hopper. Note: If the hopper is placed directly over the bean container, the beans can be collected in the container. The experiments are usually done with teams of 2 or 3 students. It usually works better if one student handles the hopper and another student catches the beans and times the experiment. Experiment variations include the following.

- various angles for the bottom section of the hopper
- different opening sizes for the hopper bottom
- different sizes of particles - using different types of beans or other materials

Given that the hopper is assembled with masking tape, the hopper can be adjusted to the different angles and opening sizes.

Discussion Questions

There are a set of questions that can be used to initiate discussion.

- Would a smaller opening or a wider opening work better for hopper design?
- How wide does the bottom opening have to be to prevent bridging?
- If the angle is 90^o, some material collects in the corners and never leaves the hopper. What angle is needed to prevent these stagnant regions that do not flow?
- How would you design the angle at the bottom of the hopper?

Real World Applications

In the discussion with the students it is emphasized that hoppers are routinely used in industrial manufacturing in the chemical, pharmaceutical, and food industries among others. Whereas liquid raw materials are often pumped from a tank, solid raw materials often come from a hopper. One problem that can be encountered is the formation of a stagnant area in the hopper where material is trapped in a corner and does not leave the hopper. In the case of a food material, this can be a significant problem. Another difficulty is when an arch of material (sometimes referred to as a bridge) forms at the hopper exit and stops the flow of material out of the hopper. While this may initially sound like a small problem, it can stop the entire manufacturing process. In practice, the opening size and the angle of the opening are two major considerations. However, there are other factors, such as humidity, that can affect the flow.

There are a variety of equipment units that can be used to feed material into a process and that control the rate at which material flows into a process. For solid materials, these are often other units such as moving belts that transfer solids from the hopper outlet to the next unit in the process. In liquid processes, there are pumps and pipes that transfer liquids from a tank to process unit. In both cases, it is essential for an engineer to know how to design the equipment for it to be reliable and for it to feed material at the desired flow rate. As in the case of the hopper where the design parameters of the hopper angle and the opening size had to be controlled, each equipment unit has design parameters that must be determined by the engineer.

Observations and Concluding Remarks

This hands-on experiment:

- allows students to determine the effect of design variables on flow rate
- introduces students to hopper flow and bridging concepts, and flow rate concepts
- allows discussion of how this data would be used to design a hopper with the desired flow rate

It is emphasized to the students that most chemical engineers do not spend much time designing hoppers, but that engineers are involved in designing equipment so that it works correctly. The hopper is just one example. In chemical engineering there are a number of equipment units that will be studied and like the hopper, they can fail and stop a manufacturing process. Part of the job is to anticipate problems and to consider various variables such as the hopper opening size and the wall angle at the bottom of the hopper. In addition, since chemical engineers are concerned with controlling flow rates, they study pumps that are used for liquid flow and methods for measuring flow rates.

This experiment can easily be adapted to create a demonstration by not measuring the time it takes for the beans to flow through the hopper. For example, it can be used to demonstrate bridging; or it can be used to demonstrate stagnant areas in a hopper by creating a 90^o angle for the hopper and putting a material of a different color in the stagnant regions and showing that it does not flow out of the hopper.

DRY GOLD PANNING DEMONSTRATION

Preparation by Instructor

The following materials are needed for the demonstration.

Pans: aluminum tins (3" – 4" diameter)

Light particles: pinto beans (or other dried beans)

Heavy particles: small pebbles

The tins can be the small aluminum pie tins available in many grocery stores. A set of 2 tins are needed for each demonstration. The beans and pebbles should be about the same size.

Before the students arrive, the tins should be set out in pairs. For each pair of tins, one tin should have a mixture of pebbles and beans added to it. In this demonstration, the dried beans represent the sand and the pebbles represent the gold. As in gold panning where the volume of the sand is much greater than the volume of the gold, the mixture is prepared so that the volume of the dried beans is at least 10 times the volume of the pebbles. The metal tins should not be full of pebbles and beans, but should just have enough material to cover the bottom of the tin. When performed in a summer camp, each student is given a pair of tins with pebbles and dried beans.

Instructions to Students

Demonstration Objective: Investigate degree of separation of beans from pebbles using density differences.

Non-industrial application: Gold panning, pebbles sometimes occur in bags of dried beans

Industrial application: Density differences are used for separations

Each student is given two aluminum tins with one tin containing a mixture of beans and pebbles. Initially students are asked to describe the differences between the dried beans and the pebbles. After some discussion, the students are told that the objective is to separate the pebbles from the beans using density differences. Size cannot be used for separation since the pebbles and the beans are approximately the same size. The students are told that this is similar to gold panning. In food processing, separating pebbles from beans is a practical issue since bags of dried beans sometime contain small pebbles.

Demonstration Procedure

The procedure is then demonstrated for the students. The students are told to slightly tilt the pan with the beans and pebbles so that the lower lip of the pan is over the catch pan, to gently shake the pan back and forth so that the beans and the pebbles move, and to tilt the pan so that some of the beans fall out of the pan during shaking. During the shaking the empty tin is used as a catch pan. This is demonstrated and then the students are then asked to try this.

Demonstration variations include the following.

- using various ratios of less dense material to more dense material
- using two materials with different density ratios (e.g. using small Styrofoam spheres for the lighter material and ball bearings for the heavier material)
- using tins with different angles

The participants can be split into separate groups and each group can be given a different variation. This is not considered an experiment since the degree of shaking is difficult to control so that it is repeatable, and since there aren't any measurable results.

Discussion with students

While the students are shaking the pans, the concept behind the separation is explained. The concept is that the more dense materials (pebbles) will move to the bottom of the pan during shaking, and that the lighter materials (beans) will move to the top as shown in Figure 2. Therefore the material that falls out of the pan will mainly be the less dense particles.

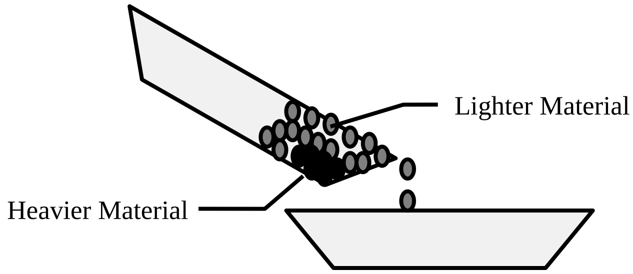

Figure 2. Schematic for separation of particles based on density.

Topics for further discussion are given below.

- Separations are important in chemical engineering.
- A sharp split is desired but not always achieved. Explain what a sharp split is.
    - Do some pebbles go into the catch pan? Is there a sharp split with this procedure?
- Explain that there are many separations in engineering. Chemical engineers find ways to improve the purification process and study the limits for various separation processes.
- Discuss the design concept of performing the panning several times in series to improve the purity of the product.
- Density differences can be used to separate liquids, e.g. oil and water.
- How can this process be improved? Will there be better separation if this process is repeated in series?

Real World Applications

In the discussion with the students it is emphasized that the separations technique used for the dry panning is the density difference, and that density differences are routinely used in industrial practice. The density differences however are not limited to solid materials.

The separation of oil and water uses the differences in the densities of the two liquids to separate them. Most people have seen this in bottles of salad dressing where there is an oil layer on top of a liquid layer that is mainly water. After shaking, the oil and water are mixed, but when the bottle is allowed to rest the mixture separates back into the two layers. This concept is used industrially to separate oil and water. In practice, the oil/water mixture is pumped into a tank and allowed to separate. One pipe from the bottom of the tank allows the water to be removed, and another pipe above the oil/water interface allows the oil to be removed. This is called decantation.

Several techniques separate solid particles from a slurry by using the differences between the solid and liquid densities. Sedimentation uses the forces of gravity to cause the denser solid particles to sink through the less dense fluid to the bottom of a tank; the clear liquid at the top of the tank can be removed through a pipe. Sedimentation tanks are often used for wastewater treatment, and removing dirt and debris from raw vegetables in food processing. In some cases, gravity is not strong enough to produce the desired separation, particularly for small particles. When gravity is not sufficient, centrifugal force is used to separate the more dense particles from the less dense liquid. Although a centrifuge will not produce a sharp split resulting in pure liquid and dry particles, it will remove almost all of the solids from the liquid and will have very little liquid in the solids. Centrifugal separators are used to separate pulp from fruit juices, to recover many crystalline materials and solid polymers from slurries, and to separate oils from water/oil mixtures.

Observations and Concluding Remarks

The dry panning demonstration:

- allows students to observe the degree of separation by dry panning
- introduces students to the concept of separating materials by differences in physical properties.

It is explained to the students that while dry panning is not a typical process in chemical engineering, separations processes are critical in chemical manufacturing. As in the dry panning, real separation processes rarely produce sharp splits, but often the degree of separation can be calculated. In chemical engineering, students learn how to choose and design separation equipment for different applications.

NSF BROADER IMPACT

The National Science Foundation (NSF) encourages researchers to address broader impacts when performing research. These are addressed by answering any combination of the following questions.

1. "How well does the activity advance discovery and understanding while promoting teaching, training and learning?
2. How well does the proposed activity broaden the participation of underrepresented groups (e.g., gender, ethnicity, disability, geographic, etc.)?
3. To what extent will it enhance the infrastructure for research and education, such as facilities, instrumentation, networks and partnerships?
4. Will the results be disseminated broadly to enhance scientific and technological understanding?
5. What may be the benefits of the proposed activity to society?" [5]

It should be noted that not all of these areas are addressed by these experiments and demonstrations; specifically Item 3 isn't addressed.

These hands-on activities address Item 1 by explaining basic particle technology concepts to high school students and by having the students participate in the activities. Although the students do not have sufficient background to understand the details of particle technology research, they can understand some fundamental concepts. Specifically, they can learn from the dry panning demonstration that materials can be separated based on density differences; and that the ratio of the particle size to the opening size could affect hopper flow.

These demonstrations and experiments address Item 2 by having students from underrepresented groups participate. In this case, the activities were used with a camp for young women, an underrepresented group in engineering, but they could easily be used with students from other underrepresented groups.

The contribution of this work to Items 4 and 5 are small, but it should be considered that not all of the students will major in science or engineering. Therefore, these demonstrations and experiments explain basic scientific concepts to the general public. It is explained that having a better knowledge of particle technology allows chemical companies to lower costs and remain competitive.

CONCLUDING REMARKS

As part of the 1 to 2 hour session with the students in the WISE camp, the first part was to talk to the students about chemical engineering and explain what chemical engineers do, what types of courses are needed for chemical engineering, where students are typically hired, what the student chapter of the AIChE offers to students, and the percentage of women typically found in chemical engineering classes. After this the students are asked if they have any questions. Typically, there are few questions. At this time the hands-on activities are introduced. During this time there is an interactive question and answer session with the discussion questions given above. At the end of the activity the students are again asked if they have any questions. This time the students are more open and there are questions both about the hands-on activity and about majoring in engineering or chemical engineering. For both the dry panning and the hopper flow activities, the students become actively involved and the noise level in the room goes up. This is particularly true for the dry panning when the beans and pebbles are being shaken in the metal tins. Although no formal assessment was performed, it was clear from the students' questions and comments that they were thinking about what would happen if an experiment or demonstration was changed and therefore they were learning some of the basic concepts in particle technology.

These activities are performed with readily available materials, are inexpensive, and are portable. While used with a summer camp, they can be used in high school class rooms. While these can be used as a demonstration by an instructor, they are designed so that students can perform them. These hands-on activities encourage student learning by getting students actively engaged. The experiments illustrate hopper flow in particle technology, and the chemical engineering concepts such as separations and purity. Both the demonstrations and experiments allow discussion of engineering design. These tangible examples of engineering problems can be used to encourage students to consider STEM careers. Furthermore, demonstrations and experiments of this type can be used to meet NSF broader impact criteria.

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