Teacher Guide
Preparation of Bio-based Polymer Films

Overview

In this series of activities, students will apply the scientific method and the 5E learning cycle to explore the preparation of bio-based polymer films. First, students will use starches derived from three different natural sources to make their own starch-based film. Students will use deduction to figure out what is the function of each of the biopolymer components and steps involved in the formation of the polymer films. Then, students will study the mechanical, optical and barrier properties of the films manufactured. Students will also correlate differences in the composition of raw materials and the final properties of the films. Finally, students will compare the features of bio-based polymer films with petroleum-based polymer films to establish differences in performance and also understand the challenges of bio-plastics to transition away from petroleum-based plastics.

Objectives

Students will

- Explore the manufacturing of polymer films using starch from different raw materials.
- Study the mechanical properties of polymer films and compare how the raw material used for its manufacture influence their final tensile strength.
- Study the optical properties of polymer films and compare how the raw material used for its manufacture affect their final opacity.
- Study the barrier properties (wettability, contact angle and water uptake) of polymer films and correlate the chemical nature of the starch to the film properties.
- Compare the properties of bio-based polymer films with oil-based polymer films and establish advantages and disadvantages of inherent to each material.

Content Standards

This lesson is appropriate for high school students and addresses the following standards:

North Carolina Essential Standards

Earth/Environmental	EEn.2.8
Physical Science	PSc.1.2; PSc.2.1; PSc.2.2
Chemistry	Chm.1.2; Chm.2.1
Biology	Bio.2.2

Next Generation Science Standards
Grades 9-12, Disciplinary Core Ideas/Practices/Cross-cutting concepts:

DCI	HS-ESS3 Earth and Human Activity HS-PS1 Matter and its Interactions
Practices	Asking questions and defining problems Planning and carrying out investigations Analyzing and interpreting data Constructing explanations and designing solutions
Cross-cutting concepts	Structure and function Stability and change Cause and effect

Time Requirements
Preparation: 30 minutes
Class-time: 2 class periods. The first period will cover the starch-based film preparation and the second period the testing of the physical and chemical properties.

Materials
Included in the kit:
Tapioca starch
Potato starch
Corn starch
Glycerin (food grade)
Vinegar (food grade)
Vernier Go Direct® Force and Acceleration probeware
Parchment paper
Dropper
Polystyrene film
Ruler
Scissors
Silicon glove
Template (rectangle: length = 21.6 cm; width = 16.8 cm)
Opacity scale

Needed, but not supplied:
600 mL PYREX™ Heavy-Duty Beaker
100 mL graduated cylinder
2 25-mL graduated cylinder
Hot plate
Precision balance (readability = 0.02 g)
Tap water
Duct tape

Safety
Beware that laboratory hot plates present dangers such as the potential for people to burn themselves or even start a fire. Remember to turn the hot plate off once you finish working with it. Do not overheat the polymer melt to avoid potential spilling of hot components. Be extremely careful when manipulating the polymer melt during the formation of the film.

Ensure that students understand and adhere to safe laboratory practices when performing any activity in the classroom or laboratory. Demonstrate the protocol for correctly using the instruments and materials necessary to complete the activities, and emphasize the importance of proper usage. Use personal protective equipment such as safety glasses or goggles, gloves, and aprons when appropriate. Model proper laboratory safety practices for your students and require them to adhere to all laboratory safety rules.

Background Information
Traditional plastics (polyethylene, polypropylene, ABS, and PET) are synthesized from petroleum by the petrochemical industry. Society relies on these plastics materials to perform every-day tasks such as packaging for food and drinks and materials for construction, electronics, and transportation.

There are many environmental concerns around how oil-based plastics are produced. Oil spills that occur during drilling and transport cause significant environmental damage on both marine and terrestrial ecosystems and are considered a form of pollution. Transforming crude oil into plastics also releases toxins into the atmosphere that are dangerous for human health. Lastly, the fact that petroleum is a source that, sooner or later, will be depleted, has led some segments of the industry to look for substitute materials.

In this context, bioplastics have emerged as an alternative for petroleum-based plastics. Bio-plastics have the potential to reduce the carbon footprint and decrease the non-biodegradable waste. Also, they have the ability to “close the cycle”, which increases resource efficiency and promotes the concept of circular bio-economy.

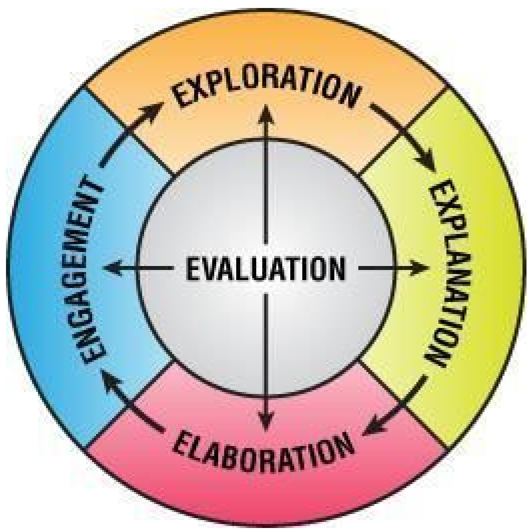
Unlike conventional plastics, bioplastics are materials derived from renewable biomass sources, such as soybean oil, and starches. Starch is the most widely used biomass source for bioplastics manufacturing. Starch is a polysaccharide made up of two components, amylose and amylopectin. These two polymers consist of glucose monomers that are joined by glycosidic bonds. Starch-based plastics can be implemented in a variety of applications, and unlike other alternative bioplastics, they can display a wide range of physical properties such as tensile strength and heat resistance.

The raw materials from which starch is derived make starch-based films an economically feasible and renewable option for bioplastics production. Starch-based films are used in food packaging and also, in consumer goods packaging of magazine wrappings and bubble films. Starch blends accounted for 18.8% of the 2.05 million tons of bioplastics produced in 2017 worldwide, and are expected to account for the largest share in the market by 2020.

Preparation

1. Photocopy the Student Guide for each student or each group, as desired.
2. Organize students into 10 groups of three. If your class size differs, adjust the size of the 10 groups accordingly.
3. Set out the materials for the experiments in a central, accessible location so students can see them and consider how they might use them. Remember, the method that they pick will determine the basic set of materials they will need.

Guiding the lesson using the 5E Learning Cycle



Engage (10 minutes)

1. Have the students brainstorm a list of plastics, films, and coatings that they encounter in their everyday life. Ask students probing questions. They may not even be aware of films and coatings, but soon they will discover their abundance. Examples of products could include: plastic bags, chip bags, coating on cell phone screens, films on solar panels, food wrapping.
2. Next, have students describe the properties of these films that make them desirable from a consumer perspective. Examples of properties could include: strength, flexibility, transparency, heat value, color, printability.
3. Show video clip to introduce the lab activity.

Explore (45 minutes)

1. Day 1: Students formulate starch-based films with the materials available (choose 2 different starches that they want to test) using the general procedure provided.

2. Teacher floats between groups to ensure student participation and understanding.

Explain (10-15 minutes)

1. Students define and explain the function of each of the components involved in the film preparation. What factors might influence the process and how?
2. Chemistry behind polymer melting (as opposed to polymerization or creating a polymer)

Elaborate (60 minutes total)

1. (5-10 minutes) Start with discussion on what types of properties are important when designing/developing films and plastics
2. Test properties. Students should try to obtain replicate measurements if possible instead of only one measurement. Properties to be tested: tensile, opacity, absorbency (Each property is a different station, with 2 groups per property - students will rotate between the 3 stations)
3. Discuss group data (create table on whiteboard, or use spreadsheet), compare groups' results, and talk about any discrepancies between data.

Evaluate (10 minutes)

1. General discussion about results, working hypotheses, how results differed and why.

Questions

1. What is the objective of the study?
2. Describe the conditions that you used in your film preparation experiment.
3. What results did you see in the experiment?
4. What is the function of each of the components added during the preparation of the polymer film?
5. What do you think is happening at the molecular level during the application of the tensile test?
6. How do the mechanical properties of the films made from the different starches compared with one another? What is the strongest film? What is the weakest film? How do you think that the chemical composition of each starch would affect the physical behavior? Do you think that non-uniformity in the film thickness among the samples might affect the results obtained? How so?
7. How do the optical properties of the films made from the different starches compared with one another? What is the most opaque film? What is the most transparent film? How do you think that the ratio of amylose to amylopectin in the native starch might affect the optical properties of the films? How so?
8. Are the polymer films prepared hydrophilic or hydrophobic? Are the films wettable or non-wettable to the same extent?
9. Does the contact angle change as the exposition time increases? If so, what is physically or chemically driving such phenomenon?

10. Is there surface damage on the film after exposure to water? What does this suggest about the barrier properties of the film? Would it be a good option to consider such material for food packaging?
11. How does the contact angle between the bio-based and the oil-based film compare? Would you consider the oil-based film as being hydrophilic or hydrophobic? Is there any change in the contact angle between the water droplet and the oil-based film with increasing time?
12. What conclusions can you draw on the basis of the data and analysis?
13. How would you change the apparatus or what experimental conditions would you use to optimize the film preparation and produce films with enhanced physical and chemical properties?

Supplemental Resources

Reading: New starch-based bioplastics arrive to the U.S. market	https://www.ptonline.com/articles/new-starch-based-bioplastics-arrive
Bioplarch: a research on starch-based bioplastic	https://www.youtube.com/watch?v=EAa514wWS6E
Reading: Starch Based-Bioplastics: The Future of Sustainable Packaging	https://www.scirp.org/Journal/PaperInformation.aspx?PaperID=84926
Physical and Chemical Investigations of Starch Based Bio-Plastics	https://lra.le.ac.uk/bitstream/2381/33021/1/Tariq%20PhD%20thesis%2013-08.pdf

Name ____________________ **Student Guide**
Date _____________________

Overview

In this series of activities, students will apply the scientific method and the 5E learning cycle to explore the preparation of bio-based polymer films. First, students will use starches derived from three different natural sources to make their own starch-based film. Students will use deduction to figure out what is the function of each of the biopolymer components and steps involved in the formation of the polymer films. Then, students will study the mechanical, optical and barrier properties of the films manufactured. Students will also correlate differences in the composition of raw materials and the final properties of the films. Finally, students will compare the features of bio-based polymer films with petroleum-based polymer films to establish differences in performance and also understand the challenges of bio-plastics to transition away from petroleum-based plastics.

Background

Traditional plastics (polyethylene, polypropylene, ABS, and PET) are synthesized from petroleum by the petrochemical industry. Society relies on these plastics materials to perform every-day tasks such as packaging for food and drinks and materials for construction, electronics, and transportation.

There are many environmental concerns around how oil-based plastics are produced. Oil spills that occur during drilling and transport cause significant environmental damage on both marine and terrestrial ecosystems and are considered a form of pollution. Transforming crude oil into plastics also releases toxins into the atmosphere that are dangerous for human health. Lastly, the fact that petroleum is a source that, sooner or later, will be depleted, has led some segments of the industry to look for substitute materials.

In this context, bioplastics have merged as an alternative for petroleum-based plastics. Bio-plastics have the potential to reduce the carbon footprint and decrease the non-biodegradable waste. Also, they have the ability to “close the cycle”, which increases resource efficiency and promotes the concept of circular bio-economy.

Unlike conventional plastics, bioplastics are materials derived from renewable biomass sources, such as soybean oil, and starches. Starch is the most widely used biomass source for bioplastics manufacturing. Starch is a polysaccharide made up of two components, amylose and amylopectin. These two polymers consist of glucose monomers that are joined by glycosidic bonds. Starch-based plastics can be implemented in a variety of applications, and unlike other alternative bioplastics, they can display a wide range of physical properties such as tensile strength and heat resistance.

The raw materials from which starch is derived make starch-based films an economically feasible and renewable option for bioplastics production. Starch-based films are used in food packaging and also, in consumer goods packaging of magazine wrappings and bubble films. Starch blends accounted for 18.8% of the 2.05 million tons of bioplastics produced in 2017 worldwide, and are expected to account for the largest share in the market by 2020.

Materials
Tapioca starch
Potato starch
Corn starch
Glycerin (food grade)
Vinegar (food grade)
Tap water
Silicon spatula
600 mL PYREX™ Heavy-Duty Beaker
100 mL graduated cylinder
2 25-mL graduated cylinder
Hot plate
Precision balance (readability = 0.1 g)
Vernier Go Direct® Force and Acceleration probeware
Opacity scale
Parchment paper
Dropper
Polystyrene film
Ruler
Duct tape
Scissors
Silicon glove
Template (rectangle: length = 21.6 cm; width = 16.8 cm)

Procedure
1. **Preparation of polymer film**
1.1. Measure 7 g of starch
1.2. Measure 60 mL of water
1.3. Measure 5 mL of glycerin
1.4. Measure 5 mL of vinegar
1.5. Mix all the components in the 600 mL beaker using the silicone spatula. Glycerin tends to be viscous and stick to the walls of the cylinder. Use a fraction of water to rinse the glycerin left behind in the cylinder.
1.6. Mix all the components thoroughly to get a white milky mixture.
1.7. Place the 600 mL beaker on the hot plate and turn on the heat at a medium setting.
1.8. Continue to stir the mixture. It must be kept homogeneous at all times. First, the mixture will start to clump up, and then it will turn into a gel, slightly opaque. Further

stirring and heating will turn the mixture into a completely clear medium, which will be referred to as polymer melt henceforth.

1.9. Once the polymer melt shows a very thick consistency and starts bubbling up, turn off the heat. The resulting polymer melt must be much more transparent and will have some air bubbles trapped inside.

1.10. Place the rectangular template below the parchment paper. Use the silicone spatula to spread out the polymer melt on the surface of the parchment paper. Make a thin layer of polymer melt to cover the rectangular area of the template (use the weight of the spatula - no need to spread the polymer melt with a lot of force). The target is to have films with around the same thickness for the different starches.

1.11. Place the parchment paper over absorbent paper and air dry the polymer film for at least two days before testing. Once dried, carefully peel off the film from the parchment paper.

2. **Film properties measurement**

2.1. **Optical properties: Opacity**

2.1.1. Place the polymer film about ½ inch above the logo marked as the reference in the opacity scale sheet provided.

2.1.2. Try to match the resulting image to one of the logos having different opacity levels in the opacity scale sheet. Report the opacity value next to the logo selected.

2.2. **Mechanical properties: Tensile strength**

For this experiment, the Vernier Go Direct® Force and Acceleration probeware will be used.

2.2.1. Carefully cut a strip of the film so that it is 1 cm wide. The test strip length should be ~6 cm. Avoid wrinkling or tearing the strip. When cutting, try to make the edges as smooth as possible. Also, cut samples with uniform thickness. Avoid the presence of air bubbles or other defects in the testing area.

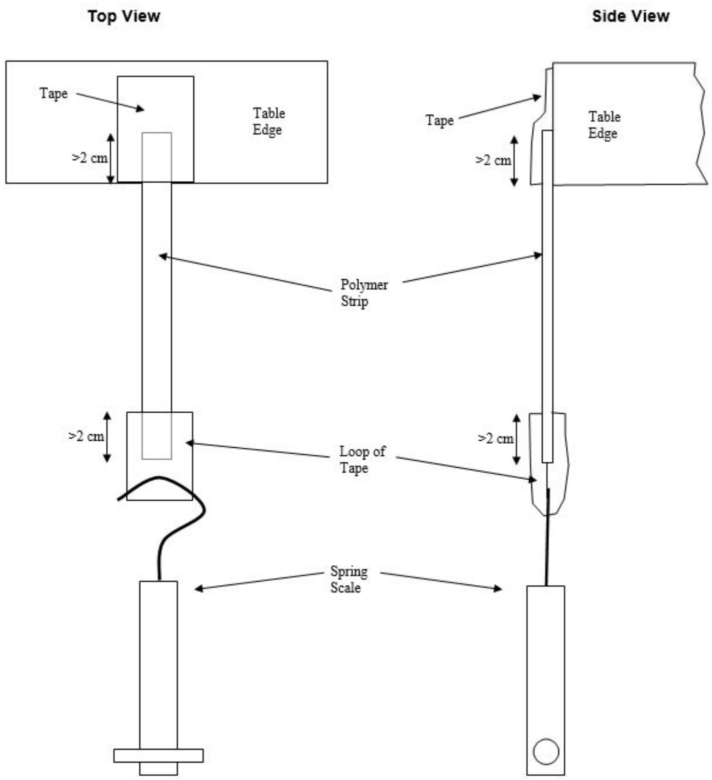
2.2.2. Using a 10 cm length of strong Duct tape, tape at least 2 cm of length of the strip to the table edge. See illustration.

2.2.3. Using about 30 cm length of strong Duct tape, attach the probeware to the other end of the film strip. The tape should loop around the sensor hook and then sandwich the bottom part of the filmstrip. See illustration. Again make sure to tape at least 2 cm of the bottom of the filmstrip.

2.2.4. Zero the probeware. Now, pull on the probeware so as to apply force along the length of the filmstrip. Apply force to the probeware at a uniform rate until the filmstrip breaks. DO NOT twist the filmstrip and always keep the film aligned to the surface while pulling. Make sure that the strip has not slipped out from the tape. If it has, the experiment is not useful. You can retry the test using the same film as long as it has not suffered any damaged.

2.2.5. Record the maximum force applied to break the filmstrip using the Graphical Analysis 4 software. Get at least two replicates of the experiment.

2.2.6. Report the tensile strength in N/cm (average force to break the strip divided by the strip width).



2.3. **Barrier properties: Wettability and Water absorption**

2.3.1. *Evaluation of water uptake*

2.3.1.1. Cut and weight a 2 x 2 cm polymer film.

2.3.1.2. Determine the weight of the film.

2.3.1.3. Submerge the film in tap water for 5 minutes.

2.3.1.4. After 5 minutes, take the film out of the water, wipe off carefully the excess water from the surface and determine the weight.

2.3.1.5. Calculate the water uptake by dividing the mass of water absorbed by the initial mass of the film. Get at least two replicates of the experiment.

2.3.2. *Comparison of wettability and surface damage between oil-based polymer films, bio-based polymer film, and paper*

2.3.2.1. Cut 2 x 2 cm samples of polystyrene, starch (the one of your preference) and paper.

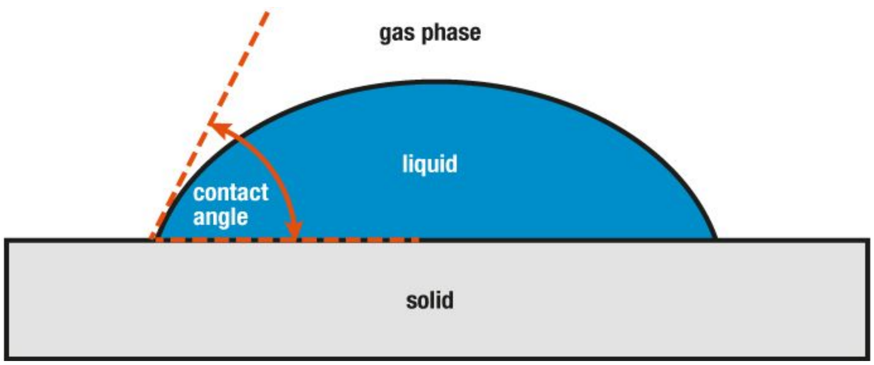
2.3.2.2. Add a water drop to the polystyrene film, the starch-based film and the piece of paper. Make sure that the surfaces are as flat as possible to avoid the droplet from moving due to a slope.

2.3.2.3. Examine the contact angle. The contact angle is the angle, conventionally measured through the liquid, where the liquid-vapor interface meets the solid surface.

See illustration. Contact angles lower than 90˚ indicate that the surface is wetted by the liquid and in such case the solid is considered as having a hydrophilic surface. Contact angles greater than 90˚ indicate that the surface is non-wettable and the solid is considered as having a hydrophobic surface.

2.3.2.4. Wipe off carefully the excess water from the film surface.

2.3.2.5. Examine qualitatively the area where the water droplet was in intimate contact with the polymer film surface.



Representation of static contact angle (ref: linses Inc., 2019)