Initial and Final Heights of Thin Films – Instructor's Version

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Date of Experiment:

OBJECTIVES

- Students will learn how varying the initial volume of solution will alter the final heights of the film strips.
- Students will create mathematical models using Microsoft Excel.

INTRODUCTION

Engineers rely heavily on modelling throughout their careers. Engineers use different models such as those based on theory and those based on experimental results. Mathematical modelling is used to optimize processes which engineers are always trying to do. The processes can be tested using modelling in order to improve them in the real world. Modelling is also used to test the feasibility of certain components or processes. Saftey is an important reason that modelling is used by engineers, so that they can determine whether or not what they are making will be safe to use. In this lab you will be focusing on mathematically modelling how different volumes of solution will vary the final heights the film strips.

When using mathematical modelling, one has to take into account independent and dependent variables. From your experience in high school and college classes you should already know that dependent variables are affected by changing the independent variables. For example, a scientist is testing the impact of a cancer drug. The independent variable would be the administration of the drug, and the dependent variable would be the impact the drug has on cancer. In this lab you will investigate to find the independent and dependent variables and apply them to a mathematical model.

In this lab, you will be creating dissolvable strips of different volumes. Each group will be assigned a specific volume of solution to create. Through this lab, you will gain a better understanding of how volume affects heights of the film strips, and some of the engineering principles behind mathematical modelling.

SAFETY CONSIDERATIONS

Make sure to wear safety goggles at all time. Laboratory safety gloves should also be worn.

MATERIALS NEEDED

- 1000 mL beaker
- Hot plate and mixer
- Magnetic stir bar
- CMC (carboxymethylcellulose)
- Sodium lauryl sulfate
- Citric acid (anhydrous)
- Glycerol
- Sucrose
- Peppermint oil
- Dropper
- Deionized water
- 3 mL syringe
- 2 Büchner (vacuum) flasks
- Funnel
- Fine mesh screen
- Vacuum tubing
- Vacuum source
- Spatula
- Stainless steel container
- Tubing and stoppers
- Vegetable oil cooking spray
- Blue food dye (Blue #40)

INSTRUCTOR'S NOTE:

Apparatus

The stainless steel container will be fabricated beforehand for the students to use. You will have to talk to the mechanical engineering technician to have these made. The steel itself is 304 grade 0.048 inches wide stainless steel with a vinyl coated brush. The stainless steel can be cut out using a water jet with 0.125 inches of tolerance for each the width and length. The sides can be bent up to form the container's shape, and then the corners will be welded together to make the container secure. The edges should be grinded down, so that they will not be sharp.

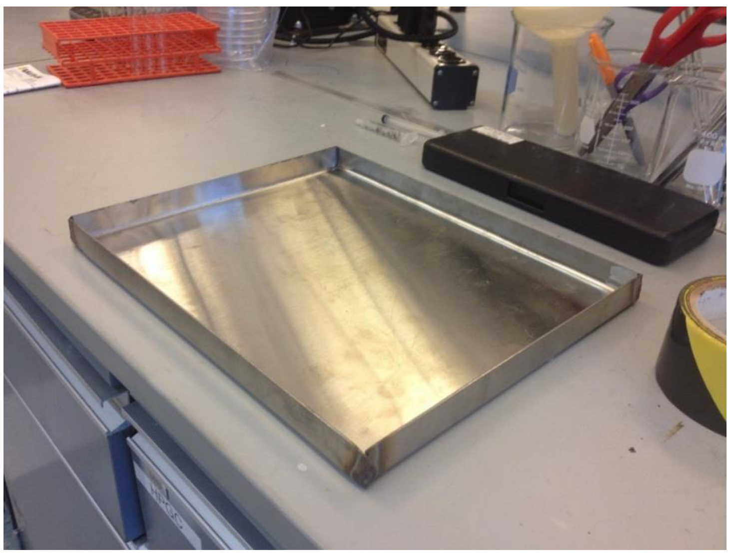


Figure 1. Stainless steel casting tray

INSTRUCTOR'S NOTE

The stainless steel container will be already fabricated for the students to use. You will have to talk to the machine shop technician to have them made. The container is 12 inches long by 10 inches wide by ¾ inches high made of 304 grade stainless steel. The container needs to be water-tight. The container size can be altered; however, the data provided at the end of the lab is for this particular size.

PROCEDURE

Table 1: Recipe for CMC preparation

Species	Weight %	Run 1 Weight (g)	Run 2 Weight (g)	Run 3 Weight (g)	Run 4 Weight (g)	Run 5 Weight (g)
CMC	1	2	4	6	8	10
Glycerol	0.6	1.2	2.4	3.6	4.8	6
Peppermint oil	0.1	0.2	0.4	0.6	0.8	1
Citric acid	0.2	0.4	0.8	1.2	1.6	2
Sodium lauryl sulfate	0.2	0.4	0.8	1.2	1.6	2
Sucrose	0.3	0.6	1.2	1.8	2.4	3
Water	97.5	194	388	582	776	970
TOTAL	100	200.0	400.0	600.0	800.0	1000.0

* Instructor's Note: Please see the Instructor's overview for specific grades of materials.

INSTRUCTOR'S NOTE

The students will use the following procedure in making the dissolvable strips. Assign each group a specific run to test, so each group has one set of data per run. Different flavorings and food dye colors can be used instead of peppermint oil and blue food dye. Also each group can be assigned different flavorings and food dye colors at the discretion of the instructor.

1. Weigh out the appropriate amounts of all powdered ingredients.
2. Add the required amount of deionized water to the large beaker. Reminder: density of water = 1 g/cm^3 at 20°C.

Figure 2. Funnel and screen setup for pouring into flask.

3. Place the beaker on the hot plate and add the stir bar. Set the heat to the lowest setting and set the stir to a low-medium rate (1out of 10).
4. Add the CMC to the water at a very slow rate, dusting the powder over the surface of the water and waiting for it to be absorbed. Once most of it is mixed in, the solution will become very viscous and trap air bubbles. Once the viscosity increases, you will need to increase the stirring intensity. **Do this slowly**.
5. Add the glycerol to the solution with the 3 mL syringe. You will need to add the appropriate volume of glycerol that corresponds to the weight shown in Table 1. (Hint: 2mL of glycerol equals 2.4g glycerol).
6. Add the remaining components to the solution similarly to how the CMC was added. At this point, the solution should be extremely viscous and appear opaque white.
7. Add three drops of peppermint oil to the solution.
8. Add one drop of blue food dye. The mixture should now be a light blue color.
9. Transfer the solution into the vacuum flask with the mesh and funnel, pouring through the mesh, to catch any large clumps of solidified product and the stir bar. Discard the solidified product. See Figure 1 for proper set-up.
10. We will now make a vacuum filtration system. The purpose of this is to de-aerate the mixture. This minimizes the bubbles in the solution. Hook the vacuum flask up to a tube and place a rubber stopper in the top of the flask. Then, connect the tube to the other vacuum flask. Next, place a stopper with an attachment into the top of the other flask and connect this to the vacuum source. See Figure 2 for the appropriate set-up. This second beaker will stop any foam from entering the vacuum.

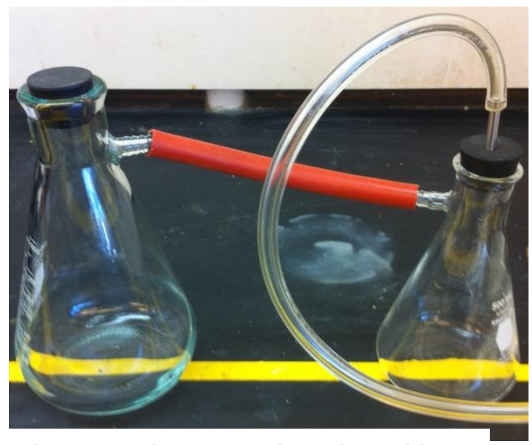


Figure 3. The setup that should be used when using the vacuum.

11. Turn on the vacuum and wait approximately 30 minutes for the entrapped air bubbles to leave the solution. The solution should slowly turn clear and may get frothy. The froth will subside.
12. While waiting for the casting process, measure the dimensions of the container in inches (Figure 3). Calculate the area of the bottom face of the container (length times the width).
13. Turn off the vacuum and disconnect the tubing from the vacuum source. Then, remove the beaker with solution from the setup.
14. Carefully pour some of the solution into a 500

Figure 4. Stainless steel container

mL graduated cylinder. This will make it easier to transfer the solution into the container.

15. Measure the volume of the solution in the graduated cylinder.
16. Spray a paper towel with vegetable oil cooking spray and wipe container with paper towel. This helps to reduce the chance of the solution sticking to the container.
17. Pour the solution into the container.
18. Allow 1-2 days for water to evaporate of from sample. The batch should appear much thinner and have a glossy finish on its surface.

INSTRUCTOR'S NOTE: Demonstrate the proper technique when cutting the strips. Also demonstrate proper use of the calipers in order to avoid the students damaging them. Students should already have a basic knowledge of Excel, but a brief tutorial may be needed to make sure students understand the basics.

Figure 5. Strips being cut

ANALYSIS

Sample Creation

1. Carefully peel the strip out of the mold with a spatula.
2. Take a ruler and measure 6 samples with dimensions of 1" x 1.5". Try to find room for samples from each of the four corners so that the samples are representative of the entire batch.
3. Using a scalpel carefully cut out the four samples.

Thickness Measurements

1. Using a caliper, take each sample and place it in the jaws of the caliper.
2. Adjust the jaws so that the sample fits snugly between them. Do not over-tighten the caliper the sample might tear. The sample should be pinched, but also be able to slide out from between the jaws when a small force is applied to it.
3. Record your results and repeat for all samples.

Figure 6. How to use calipers

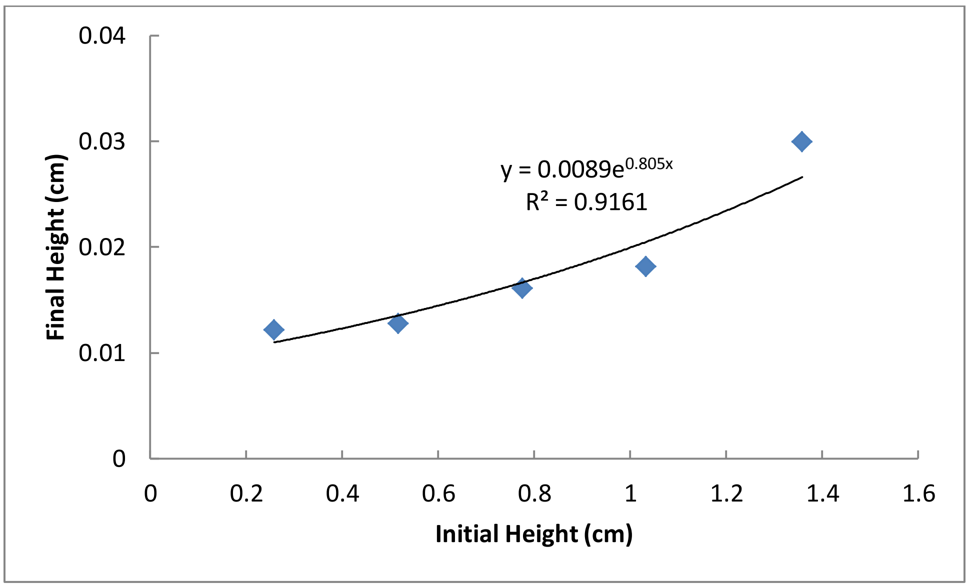
Statistical Analysis

1. Collect data from every group.
2. Calculate the mean, standard deviation and range of the final heights for each volume of solution.

Modeling Initial versus Final Height

- To empirical model the initial versus final height you will use Microsoft Excel.

1. Collect data of average final heights from all groups.
2. Make a column for the volume of the initial solution added to the drying container.
3. Create an equation to calculate the initial height based on the volume of the solution and the area of the container.
4. Make two columns; one for the initial height and one for the final height of the thin film.
5. Create a scatter plot of the Initial versus Final height.
6. Label axes and title graph accordingly with units.
7. Add trendline with equation and R^2 value. Print this out and include with your laboratory report.



INSTRUCTOR'S NOTE

The graph above is an example of what a plot of the data should look like.

QUESTIONS

INSTRUCTOR'S NOTE

The answers to each question, as well as the correct graph, are provided. Other questions or assessment material may be used in addition to or supplementary to the questions below. These questions were generated to gauge the knowledge the students should have learned over the course of this experiment.

1. Is the calculated initial height of the strips equal to the actual final height of the strips? Explain your reasoning.

Ans: The calculated initial height of the strips will be different from the final height because of the loss of water through evaporation. Thus, as water evaporates from the strips, the height will decrease. Once the strips are fully dry, evaporation has stopped, the heights should be different. Also some solution can be lost through the transferring from the graduated cylinder to the container, so the calculated initial height will be different from the actual.

2. Based on your graph; what was your trendline equation? What do x and y terms represent in this lab?
   Ans: The trendline equation is shown in the above graph. The "x" term represents the calculated initial height of the strips. The "y" term represents the average final height of the strips after drying.
3. Using your model, what would be the final film thickness in millimeters, if 750mL of solution was added to a flat container with the dimensions of 45cm by 30cm?
   Ans:

$$h_i = \frac{V}{A}$$

$$h_i = \frac{750\ mL * \frac{1\ cm^3}{1\ mL}}{(45 * 30)cm^2}$$

$$h_i = 0.556\ cm * \frac{1\ in}{2.54\ cm}$$

h_i = $= 0.219\ in$

$$h_f = 0.131 * 0.219^2 - 0.536 * 0.219 + 0.0095 = 4.04 * 10^{-3} in$$

4. Using your initial volume, calculate the final volume of the solution based on your trend-line. Does your calculated final volume match the experimental final volume? Calculate the percent difference.
   Ans: This is sample data collected in this lab.

V_i (mL)	h_i (in)	h_f (in)	V_f (mL)
200	0.10171	0.00478	9.34
400	0.20341	0.00502	9.87
600	0.30512	0.00632	12.43
800	0.40682	0.00713	14.02
1000	0.50853	0.0171	33.63

$A_{pan} = (10\times 12)\ in^2$ $A_{pan} = 120 in^2$

The equations needed to solve for the initial and final height, and the final volume are listed below:

$$h_i = \frac{V_i * \frac{1\ cm^3}{1\ mL}}{A_{pan}} * \frac{0.0610237\ in}{1\ cm}$$

$$h_i = \frac{600\ cm^3}{774\ cm^2}$$

$$h_i = 0.305\ in$$

$$h_f = 0.131 * 0.305^2 - 0.536 * 0.305 + 0.0095 = 5.34 * 10^{-3} in$$

$$V_f = (A_{pan} * h_f) * \left(\frac{16.387064 cm^3}{1 in^3} \times \frac{1\ mL}{1 cm^3}\right)$$

$$V_f = (120\ in^2 * 5.34 \times 10^{-3} in) * \left(\frac{16.387064\ cm^3}{1\ in^3} * \frac{1\ mL}{1\ cm^3}\right) = 10.5\ mL$$

Percent difference:

$$\frac{/Theoretical - Experimental/}{Experimental} = \%Difference$$

$$\frac{/12.43 - 10.5/}{10.5} = \%Difference$$

$$\%Difference = 18.38\%$$

5. The Pinkman Company has hired you as an employee in his business of making dissolvable "candy" film strips called Berry Blue. You know that the film strips have the dimensions of 1 cm long by 0.9 cm wide by 0.001 cm thick. These candy strips are currently made in a container with the dimensions 1 ft long by 4 ft wide.

   a) You are tasked with determining how many strips the current container can make. Round your answer to the nearest strip. **Ans:**

   $$A_{strips} * n = A_{pan}$$

   $$A_{strips} = (1.0 * 0.9) cm^2 * \frac{0.5500013\ in^2}{1\ cm^2} * \frac{1\ ft^2}{144\ in^2}$$

   $$A_{strips} = 9.6875 * 10^{-4} ft^2$$

   $A_{pan} = L \times w$ $A_{pan} = (1 \times 4)\ ft^2$ $A_{pan} = 4\ ft^2$

   $$n = \frac{A_{pan}}{A_{strips}}$$

   $$n = \frac{4\ ft^2}{9.6875 * 10^{-4} ft^2}$$

   n= 4129 strips

b) Your boss wants to increase the amount of film strips per batch to 4250. The film strips still have the same dimensions as before. You are to determine the dimensions of the new container assuming that the length and width have the same ratio as the current container.

c) **Ans:**

A_{pan}= n × A_{strips} $A_{pan}= 4250 \times 9.6875 \times 10^{-4}\, ft^2$ A_{pan}= 4.117 ft^2

A_{pan}= L × w $L = \frac{W}{4}$ $A_{pan} = \frac{W}{4} \times w$ $w = \sqrt{4.117 ft^2 * 4}$ <u>w = 4.058 ft</u>

$\frac{Apan}{w} = L$ $L = \frac{4.117 ft^2}{4.058\, ft}$ <u>L = 1.015 ft</u>

d) Given that the final thickness of the film strips is 0.05 cm, you are to determine the volume of solution needed to produce 4250 strips using the new container. **Ans:**

$$h_f = 0.05\, cm * \frac{in}{2.54\, cm} = 1.97 * 10^{-2} in$$

$$h_i = 0.55\, in$$

$$V_i = A_{pan} * h_i$$

$$V_i = 4.117\, ft^2 * 0.55\, in * \frac{1\, ft}{12\, in}$$

<u>V_i = 0.190 ft^3</u>

6. Using your initial volume of solution and a mass balance, determine the final height of the strips, in centimeters, assuming that only water evaporates off. The density of water is 0.9982 g/cm^3. Calculate the percent difference. **Ans:**

Example using 600mL of solution:

$m_i = \rho \times V_i$ $m_i = 600mL \times 0.9982 \frac{g}{mL}$ $m_i = 598.82g$

$m_i = m_v + m_l$

Using final moisture content from creation lab the vapor fraction of water can be found.

x_{H2O} = 0.02 y_{H2O} = 1- x_{H2O} y_{H2O} = 0.98

Use vapor fraction to find mass of water vapor that left system.

$m_v = y_{H2O} \times m_i$ $m_v = 0.98 \times 598.82g$ $m_v = 586.94g$

Solve for mass of water in solution

$m_l = m_i - m_v$ $m_l = 598.92g - 586.94g$ $m_l = 11.978g$

Solve for the final volume to find the final height

$$V_f = \frac{m_l}{\rho}$$

$$V_f = \frac{11.978\ g}{0.9982\ \frac{g}{mL}} \times \frac{1\ cm^3}{1\ mL}$$

$$V_f = 12cm^3$$

$$h_f = \frac{V_f}{A}$$

$$h_f = \frac{12\ cm^3}{120\ in^2 \times \frac{2.54^2 cm^2}{1\ in^2}}$$

$$\underline{h_f = 0.0155cm}$$

Percent Difference:

$$\frac{/Theoretical - Experimental/}{Experimental} = \%Difference$$

INSTRUCTOR'S NOTE: The experimental value is the average final height that was measured using calipers.

$$\frac{/0.0155 - 0.0160/}{0.0160} = \%Difference \qquad \underline{\%Difference = 3.4\%}$$