

## Modeling Evaporation of Water in Thin Films – Instructor’s Version

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Date of Experiment:

### OBJECTIVES

- Students will learn how to use various functions in Microsoft Excel.
- Students will learn how to create mathematical models using Microsoft Excel.
- Students will learn about a mass balance through evaporation.

### INTRODUCTION

Separation processes are an important aspect in engineering science and design. There are various types of separation processes which include absorption, stripping, evaporation, and adsorption. Purifying flour, extracting caffeine from coffee or tea, refining ore to obtain a metal; these are all examples of separation processes. In this lab, the separation process that occurs is evaporation of water from the film strip solution. Evaporation is a separation process of heating a liquid mixture to drive off the more volatile compound as a vapor. By becoming a vapor, the substance leaves the system. Separation processes are common practice in industry, so they have a multitude of uses in every discipline of engineering.

Engineers are often tasked with developing models of different processes, so they can be simulated. Engineers typically develop mathematical models for different processes. Mathematical models are used to determine a variety of parameters and outcomes in these processes and simulations. Models are also useful in determining feasibility and safety of a project. An example would be automobile crash tests to determine the safety of a vehicle before it goes on the market. There are many modeling programs available in industry. One program that can be used for modeling is Microsoft Excel.

In this lab the students will combine the basic principles of a mass balance and computer modeling to determine the final height of the film strips based on the evaporation of ingredients using Microsoft Excel.

### SAFETY CONSIDERATIONS

Follow proper computer laboratory safety procedures. Make sure to have no open food or water containers near the computers.

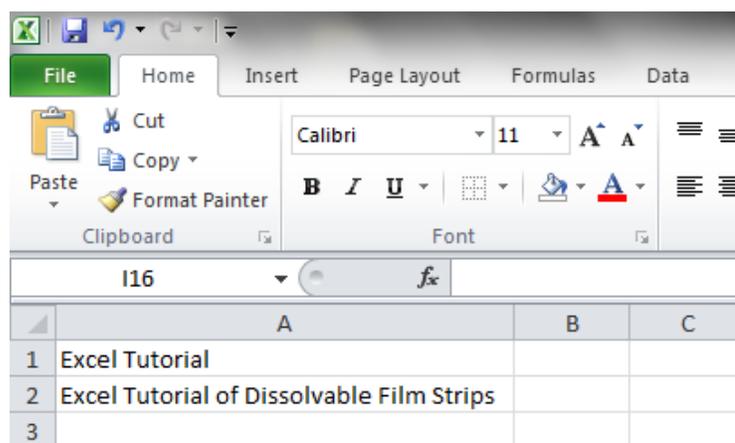
## PROCEDURE

### INSTRUCTOR'S NOTE

This is a computer laboratory using Microsoft Excel. Reserve a computer lab in advance for this laboratory or have students bring laptops to class in order to complete this laboratory. Also throughout the tutorial the units should be kept in cgs. Use the version of Microsoft Excel that is on the computers in the computer laboratory.

#### *Excel Tutorial*

1. Open Microsoft Excel.
2. Double-click on the first cell A1 and type "Excel Tutorial". Notice that the text goes into the cell B1.
3. To fix this go to the line dividing cell A and cell B. Double click on this line to expand cell A1.
4. Sometimes the text you type will be too long to do this. Type "Excel Tutorial of Dissolvable Film Strips Evaporation" into cell A2. Double click to expand cell A2. Notice that this cell is now the length of 5 cells.



**Figure 1: Text in A2 after expanding cell**

5. Undo the double clicking by either clicking the undo button, or using the shortcut Ctrl + z. Instead of double clicking to expand the cell, click on cell A2. Then on the home toolbar, click wrap text. See how the text only takes up one cell now.

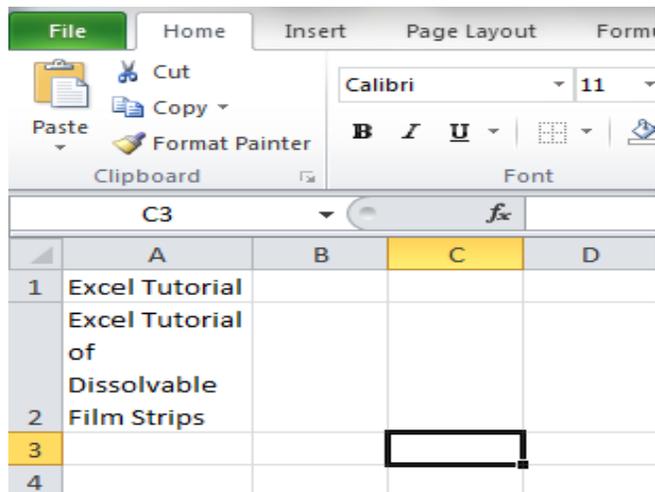


Figure 2: Cell A2 after text wrap

- Now go to cell B1 and type the number 5 and in cell C1 type 10. Go to cell D1 and type “= B1 + C1”. This is a simple equation that can be typed into Excel. Excel is very useful for solving complicated equations.

### *Mass Transfer of Water from Film Strips*

#### INSTRUCTOR’S NOTE

Now would be a good time to discuss the problem that the students are going to solve. Also discuss the basics of evaporation that apply to the problem as supplemental material to the tutorial below.

When the film strips are drying, water is evaporating from the solution. However, it is hard to determine how much water has evaporated from the strips. This is assuming that only water is evaporating. In order to determine the amount of water lost, follow the tutorial below.

- For this problem, first delete the current sheet you are on, “Sheet 1”, by going to the tab that is labeled “Sheet 1”, and then right click and select delete. Go down to the tab that is labeled “Sheet 2” and rename the sheet to “Case 1”. This sheet will be turned in and graded at the end of the laboratory.
- Now you will begin by filling in the headers for columns A-L, so that the workbook resembles Figure 3. Remember to use wrap text and expand the cells when necessary. If you notice, there are some headers with subscripts. To make a letter subscript, type it into the cell and then highlight it. On the home toolbar go to Font and click on the little arrow in the bottom right. A menu will appear, and in the “Effects” section click on the box next to subscript. Then click OK.

	A	B	C	D	E	F	G	H	I	J	K	L
1	$V_i$ (mL)	$\rho$ (g/mL)	$m_i$ (g)	Moisture Content	$y_{H_2O}$	$m_v$ (g)	$m_l$ (g)	$V_f$ (cm <sup>3</sup> )	$A$ (cm <sup>2</sup> )	$h_f$ (cm) Theory	$h_f$ (cm) Experimental	%Difference
2												
3												

Figure 3: Headings to Columns A-L

- The volume of solution that is being used is 600 mL, so in cell A2 type 600. Remember 1 mL is equal to 1 cm<sup>3</sup>. The density of the solution is very similar to water because the solution is 97% water. In cell B2 type 0.9982 g/mL.
- In order to determine the initial mass of the solution you need to refer back to the equation for density.

$$\rho = \frac{m}{V} \quad (1)$$

When it is rearranged, it can be used to solve for mass. In cell C2 type, “=A2\*\$B\$2”. The reason to that B2 is typed as \$B\$2 is because using the dollar signs in Excel allows the program to acknowledge that the number is constant.

**Now would be a good time to save. Save the workbook as LastName\_Modeling\_Evaporation.**

- Think back to the Creation of Dissolvable Strips Lab. In that lab you had to determine the final moisture content of the film strips. Flip through your notes to find the moisture content of your strips. If you cannot find it or do not remember, just use 0.02. Type this number into cell D2. The 0.02 is the final moisture content in the strips or 2% water is left in the strips. That means that 98% of the water initially in the strips has evaporated off. So, in cell E2 type 0.98 for the fraction of water that has left the solution.
- To determine the final mass of the solution you will first have to find the mass of water that has evaporated off. In order to do this a mass balance is needed. A simple mass balance is as follows:

$$m_i = m_v + m_l \quad (2)$$

This mass balance demonstrates that the initial mass of the solution,  $m_i$ , is equal to the final mass of the water vapor,  $m_v$ , plus the final mass of the solution  $m_l$ . In

order to determine the mass of the water that evaporated you need to use this variation of the mass balance:

$$m_v = y_{H_2O} \times m_i \quad (3)$$

This mass balance shows that the mass of the water that evaporated equals the fraction of water that evaporated,  $y_{H_2O}$ , multiplied by the initial mass of the water  $m_i$ . So, in cell F2 type, “=C2\*E2”. Now that you have the mass of the evaporated water, you can solve the mass balance to determine the final mass of the solution. In cell G2, “=C2-F2”, should be typed.

**Make sure you remember to save periodically.**

7. In order to determine the final height of the strips, you must first determine the final volume of solution. The density equation can be used again, but this time it should be manipulated to solve for volume. In cell H2 the equation should be, “=G2/B2”. In order to determine the final height of the strips the following equation is used:

$$h_f = \frac{V_f}{A} \quad (4)$$

The final height of the strips is calculated by dividing the final volume of solution by the area of the base of the casting tray. The area of the pan is 120 in<sup>2</sup> or 774.19 cm<sup>2</sup>. Since you have been using metric units thus far, enter 774.19 into cell I2.

So, in cell J2 the equation above should be entered, “=H2/I2”.

Instead of having to type dollar signs each time, you can use the shortcut. Type the equation into cell J2 again, but this time type J2 and then hit F4. This is a shortcut for adding dollar signs to number. Remember, this is the theoretical final height of the strips.

8. To compare the theoretical final height to the experimental final height of the film strips, you will use the percent difference formula below:

$$\%difference = \frac{abs(Theoretical - Experimental)}{Theoretical} \times 100 \quad (5)$$

This equation shows that the percent difference is equal to the absolute value of the difference between the theoretical height you calculated and the experimental height that was measured in lab, divided by the theoretical value. Multiplying by

100 turns the value into a percent. An experiment was run, and the final height of the strips was measured to be 0.01653 cm. Type this value into cell K2.

- For the percent difference, type “ $=((ABS(J2-K2))/J2)*100$ ”, into cell L2. Excel simplifies absolute value into “ABS”. Make sure you have the necessary parantheses or the equation will not work.

If you did not know the shortcut for absolute value in Excel, you can always find equation from the Formulas toolbar. You can go to this toolbar and under Math&Trig, absolute value is the first formula given.

- Highlight cells J2-L2. Now go to the Home toolbar and in the Font section there is a paint bucket, click on it to highlight the cells. You can change the color to whatever you would like by clicking on the arrow next to the bucket and seletcting a color. With the three cells still highlighted go to the Font section and in between the pain bucket and underline buttons is the border button. It should currently display bottom border. Click on the arrow next to it and go down to outside borders and click on it. Then click on the border button to add a border to your cells.

## INSTRUCTORS NOTE

Below is a sample spreadsheet for this computer lab.

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	$V_i$ (mL)	$\rho$ (g/mL)	$m_i$ (g)	Moisture Content	$y_{H_2O}$	$m_v$ (g)	$m_l$ (g)	$V_f$ (cm <sup>3</sup> )	$A$ (cm <sup>2</sup> )	$h_f$ (cm) Theory	$h_f$ (cm) Experimental	%Difference	
2	600	0.9982	598.92	0.02	0.98	586.94	11.978	12	774.19	0.015500031	0.016053	3.44	
3													
4													
5													

## Questions

- In this lab it was assumed that only water evaporated. Was this a correct assumption to make? Based on the formulation of the film strips does the assumption make sense? Explain.

**Ans:** The assumption that only water evaporated is correct. The major liquid ingredient of the strips is water, so it makes sense to assume that water is the

only ingredient that evaporates. Peppermint oil and glycerol both contain 0.1% water, so they are negligible contributors to evaporation. Since the other ingredients are stable solids, the water is the only ingredient that readily evaporates at room temperature.

2. We used computer modeling in this lab to determine the mass of water that evaporated from the strips instead of actually performing the experiment. Is it more useful to model the experiment or actually run the experiment? Explain your reasoning.

**Ans:** It is more useful to model an experiment as opposed to running it. This is because running an experiment can cost both time and money. Also running an experiment wastes resources, personnel, supplies, and energy. Modeling is a much more efficient way to determining if a product or process will work because it requires a one-time cost to buy the necessary programs.

3. Do you think that the percent difference between the experimental and theoretical heights is within the acceptable margin? Why or why not?

**Ans:** I think that the percent difference between the theoretical and experimental heights is within the acceptable margin. The percent difference was found to be 3.44%, so there are very small errors between the two. Thus, the model is accurate.

4. You are working at Dexter's Lab Consulting firm. You are looking into a new product for a client. They are a small company without a lot of funds or equipment. Your client wants you to determine the final height of their new bacon flavored breath strips through computer modeling.

- a. The volume of solution they are using is  $1000 \text{ cm}^3$ . The polymer they use is hydrophilic, meaning it readily absorbs into water. The deionized water used has a density of  $1.001 \text{ g/cm}^3$ . The area of the container is  $1500 \text{ cm}^2$ . Using the model you created calculate the height of the strips.

**Ans:**  $h_f = 0.013 \text{ cm}$

- b. Your client now wants you to scale the production of the strips up to a volume of solution of  $2000 \text{ cm}^3$  given a container area of  $2000 \text{ cm}^2$ . They want the final height of the strips to  $0.018 \text{ cm}$ . Determine the theoretical height of the new strips, and explain to your client if it is feasible or not.

**Ans:**  $h_f = 0.0267 \text{ cm}$

$$\% \text{ difference} = \frac{(h_f - h_e)}{y} \times 100$$

$$\%difference = \frac{0.0267cm - 0.018cm}{0.0267cm} \times 100$$

$$\%difference = 32.58\%$$

The scale up is not feasible because it is outside of the acceptable range based on the model used.

- c. The client decides that they want to use another polymer that is less hydrophilic than the current polymer. You are tasked with figuring out if your model can be used to figure out the final height of the strips, and if not, develop a new model to use.

**Ans:** The model used is still relevant to use with the new polymer. However, the model may need to be changed slightly, depending on the characteristics of the new polymer.