We All Scream For Ice Cream!
Demonstration of Heat Transfer via the Formation of Ice Cream through Various Barriers

CHE 342
12/03/2012

Kyle Cook
Jackie Reimann
Michael Shook
Harris Tucker

-2 for not having group # on
+2 for prelabs

35/38

Very nice report.
Introduction

Ice cream, a delicious treat of many varieties prepared with a wide range of methods, has been a dessert staple in various cultures for centuries. From the Persian Empire’s use of snow to solidify grape juice concentrate to its first cream-based ancestral recipe of 18th century England, ice cream’s evolution throughout history to the commercially-sold carton of today is well-versed. Despite the numerous ways of formulating frozen desserts, every method undoubtedly shares a common principle — they all employ key fundamentals of heat transfer. Heat transfer operates primarily in two energy transfer modes: convection, or transfer between a surface and an adjacent fluid, and conduction, transfer driven by a temperature gradient through a specified material.

In the following experiment, we will explore the relative contributions of both modes of transfer in the forming of homemade ice cream and determine whether the process is convection or conduction dominated. To do so, students will solidify a mixture of essentially milk and sugar in various containers (sandwich-sized Ziploc bag, plastic Tupperware container, and tin soup can) surrounded by an ice and salt mixture in a gallon-sized Ziploc bag. The colligative properties of salt allow for a lower freezing point of water, creating a larger temperature gradient (and hence, acceptably quick experimental procedure). Furthermore, we will investigate the reasoning behind these conclusions based upon following heat transfer theory and reasonable assumptions made about the ice cream/container system.

Background/Theory

In the case of this particular experiment, transfer by conduction is accomplished via the molecular interactions within the container material (i.e. the smaller plastic bag). Somewhat intuitively, heat travels from regions of high energy (or high temperature) to regions of lower energy; in this way, the heat from the comparatively warmer milk and sugar mixture will transfer across the container’s barrier to the much colder salt and ice surroundings. Under Fourier’s Law, the governing equation of conduction, the rate of heat transfer is dependent upon three primary variables: the surface area of the material, the conductivity of the material, and the temperature gradient of the system.

The other relevant mode of transfer is convection, which involves energy exchange between the container’s surfaces and relevant fluids (salted ice and milk/sugar mixture). In this particular experiment, this is namely forced...
convection, in that the fluids are forced to pass over the container’s surface by the student’s vigorous mixing of the system.

For the sake of this experiment’s simplicity, many assumptions were made with regard to transfer by both conduction and convection:

1. The system must be considered closed and steady state, although a system such as this would closer adhere to unsteady state transfer.
2. Conduction is assumed to occur only in direction perpendicular to the ice cream mixture’s container.
3. The thermal conductivity (k) of each container’s material is constant.
4. The convective heat transfer coefficients (h) of both adjacent substances (salted ice and milk-sugar mixtures) are constant and assumed to be simply ice and milk, respectively.

Given these assumptions, the following equations may be derived:

\[ Q_{\text{conduction}} = \left( \frac{kA}{L} \right) \Delta T \]

\[ Q_{\text{convection}} = (hA)\Delta T \]

where \( "k" \) = thermal conductivity constant, \( "h" \) = convective heat transfer coefficient

\( "A" \) = surface area of transfer layer, \( "L" \) = thickness of transfer layer

and: \( h_{\text{milk}} = 2.10 \frac{W}{(m^2)K} \), \( h_{\text{ice}} = 2.19 \frac{W}{(m^2)K} \), \( K_{\text{plastic}} = 0.45 \frac{W}{(m^2)K} \), \( K_{\text{tin}} = 67 \frac{W}{(m^2)K} \)

The fundamental discrepancy in these assumptions is that of a steady state system. In reality, because the container of ice cream ingredients is exposed at an instant to the colder surroundings, the ice cream’s temperature is a function of both position and time (instead of only position, as in steady state). The dimensionless parameter known as the Biot modulus (abbreviated “Bi”) illustrates the relative dominance of each mode of transfer in an unsteady state process, and is given by:

\[ Bi = \frac{V}{\frac{Ak}{1}} = \frac{\text{[conductive (internal) resistance]}}{\text{[convective (external) resistance]}} \]

where \( "V" \) = volume of container material alone

If the calculated Bi value of a system is less than 0.10, heat transfer in that system is considered to be entirely convection dominated. It is hypothesized that, because of the thinness of each container, the temperature gradient is
in any practical sense equal to zero. Because of this, students should find that the time taken to freeze their ice
cream, regardless of which container material used, to be relatively equal, assuming similar effort in mixing (i.e. 
equal forced convection). If significant time differences are witnessed, students should elaborate on this in terms of 
any variable factor in the system, such as the applied force of mixing, amount of salt (affecting the surrounding 
temperature), amounts of each ingredient, etc.

**Materials** *(sufficient for medium-sized class of 30)*

Table 1. Experimental supplies and materials

<table>
<thead>
<tr>
<th>Item Name</th>
<th>Quantity</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic bags (gallon and sandwich)</td>
<td>30 of each type</td>
<td>$4.00</td>
</tr>
<tr>
<td>Tin soup cans (recycled)</td>
<td>10</td>
<td>$0.00</td>
</tr>
<tr>
<td>Duct tape (to seal soup cans)</td>
<td>1 small roll</td>
<td>$2.99</td>
</tr>
<tr>
<td>Small plastic Tupperware containers</td>
<td>6</td>
<td>$2.50</td>
</tr>
<tr>
<td>Ice</td>
<td>5 lb.</td>
<td>$2.99</td>
</tr>
<tr>
<td>Kosher salt</td>
<td>1 box</td>
<td>$1.79</td>
</tr>
<tr>
<td>Plastic spoons</td>
<td>30</td>
<td>$1.79</td>
</tr>
<tr>
<td>Insulated winter gloves</td>
<td>(students bring their own)</td>
<td>$0.00</td>
</tr>
<tr>
<td>Whole milk</td>
<td>2 gallons</td>
<td>$5.00</td>
</tr>
<tr>
<td>Granulated sugar</td>
<td>1 box</td>
<td>$2.59</td>
</tr>
<tr>
<td>Vanilla extract (or other flavors)</td>
<td>1 small bottle</td>
<td>$1.29</td>
</tr>
</tbody>
</table>

**Total Cost: $24.94**

**Experimental Procedure**

Students will work in small groups of three, each receiving a different container (i.e. thermal barrier) with which he or she will mix ingredients -- small plastic Ziploc bag, plastic Tupperware container, or aluminum soup can.
(1) Blend together mixture of ½ cup milk, 1 tbsp. granulated sugar, and ½ teaspoon vanilla extract in designated small container.

(2) Fill a gallon-size plastic Ziploc bag with ample ice (4 cups) and salt (4 tbsp.) -- additional ice and salt decreases time necessary for freezing.

(3) Place enclosed small container with ice cream mixture inside gallon-sized Ziploc bag. Make sure to seal each bag before beginning to shake contents.

(4) Mix vigorously until mixture solidifies -- be sure to record time for solidification.

Because this may take up to 10 minutes, students may travel to other stations during mixing process. Gloves are also encouraged, as contents are below-freezing.

(5) Record freezing time and compare with other group members. Briefly discuss how you think using different materials affected your results, and complete the following questions applying heat transfer theory learned earlier.

(6) Enjoy your delicious treat!

**Achieved Outcomes**

Table 2. Experimental results across two trials for all three available container materials

<table>
<thead>
<tr>
<th>Container material</th>
<th>Trial 1 (min)</th>
<th>Trial 2 (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic Ziploc bag</td>
<td>9:16</td>
<td>8:09</td>
</tr>
<tr>
<td>Plastic Tupperware container</td>
<td>10:03</td>
<td>10:35</td>
</tr>
<tr>
<td>Tin soup can</td>
<td>10:45</td>
<td>11:43</td>
</tr>
</tbody>
</table>

Due to the minimal thickness of conductive material in the plastic bag, Tupperware container, and metal soup can, our hypothesis that the process of making ice cream would be essentially solely convection-driven was valid. After timing the length to form ice cream in each of the three containers, the values were extremely close to one another (approximately 6-8 min.) Variation in times could also have been caused by the amount of force during the shaking step of the procedure. This was relatively controlled by constant, equal shaking throughout the process; therefore, our assumptions of steady state do not have significant detriment to the experiment.
We All Scream for Ice Cream!

Group #19

Monday December 3, 2012

Experimental Lab Worksheet:

- Record and compare the time it took for your ice cream to freeze with that of your friends... Do your times vary by a lot?

MATERIAL (circle one): plastic Ziploc bag / plastic Tupperware / tin soup can

TIME: ______:______ [min:sec]

- After comparing your times, you should have noticed that they are the almost the same. This means that out of the three forms of heat transfer (radiation, conduction, convection), the experiment was driven by convection. Since the thickness of the container did not play a huge role in this process, the conduction should be negligible. If you witnessed a significant time difference, it may be due to the amount of force used during shaking or using more salt than was instructed.

- Now that you are a pro at making ice cream, see if you can calculate the heat loss (Q) of this experiment. Which heat loss equation should be used (circle one)?

\[ Q = \left(\frac{hA}{L}\right)\Delta T \quad \text{or} \quad Q = (hA)\Delta T \]

- Next, calculate your experiment’s Q value based on the appropriate equation you chose above and the following given values (you may not need all of them). Your answer should be negative since heat is leaving your ice cream mixture:

\[ h_{\text{mil}} = 2.10 \frac{\text{W}}{(\text{m}^2)\text{K}}, \quad h_{\text{ice}} = 2.19 \frac{\text{W}}{(\text{m}^2)\text{K}}, \quad k_{\text{plastic}} = 0.45 \frac{\text{W}}{(\text{m}^2)\text{K}}, \quad k_{\text{tin}} = 67 \frac{\text{W}}{(\text{m}^2)\text{K}}, \quad A_{\text{ziploc}} = 0.05 \text{ m}^2 \]

\[ A_{\text{tupperware}} = 0.08 \text{ m}^2, \quad A_{\text{can}} = 0.03 \text{ m}^2, \quad T_{\text{ice}} = -3.0 \text{ deg C}, \quad T_{\text{icecream}} = 15.0 \text{ deg C} \]

\[ Q = \quad \text{[Watts]} \]
We All Scream for Ice Cream!

Group #19

Monday December 3, 2012

PRE-LAB QUESTIONS:

1. What ingredients go into making ice cream and what is the state of this mixture prior to using the ice to bind the ingredients together?

   Milk, sugar, and optional flavoring. This mixture is a liquid at the start of the experiment.

2. a) How do you change the liquid solution, like the ingredients in ice cream, into a solid solution?

   You change a liquid into a solid by freezing the solution. In this experiment, the ingredients are cooled by placing them into a cold environment (bag of ice) which lowers the temperature of the mixture below its freezing temperature.

   b) Are there any other ways to change the phase of the solution without lowering the temperature?

   Physical alterations like changing the pressure can affect the freezing point. Lowering the pressure decreases the freezing point. If the pressure is low enough it can cause the liquid to freeze at a temperature above its normal freezing temperature. Since everyone is working on the experiment under the same pressure conditions, we don’t need to consider the pressure in affecting the freezing point temperature.

3. Why is the salt added to the bag of ice? Why is kosher salt used instead of table salt?

   If salt wasn’t added to the bag of ice, the ice would melt at 32 degrees Fahrenheit. The addition of salt lowers the freezing point of the ice, so more energy has to be absorbed for the ice to melt. This makes the ice colder and allows for it to cool the ice cream mix that has to be at around 27 degrees Fahrenheit to freeze.
Kosher salt is used because the salt crystals are larger than that of table salt. The larger crystals take longer to dissolve in the water of the ice, which makes it cool more evenly and creates a smoother ice cream.

For this experiment to work the ice cream mixture must undergo heat transfer. Heat transfer is roughly defined as the movement of energy from an object of high temperature to an object of lower temperature. For this experiment, our object of high temperature is the (ice cream mixture/ice-salt mixture), which is transferring its heat to the colder (ice cream mixture/ice-salt mixture). (Circle the correct answer for each)
Works Cited


