Investigation of the Effects of Temperature Variation on Freezing Speed: Does Hot Water Freeze Faster Than Cold Water?

Kathryn Sharpe
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1 Introduction

Originally posed by a young boy, the problem of hot water freezing faster than cold water has boggled the minds of many. One would think that the lower the temperature of the water to be frozen, the less time it will take to freeze, as it begins closer to its end point that a warmer sample does. However, the problem is not as simple as it seems.

A wide variety of experiments have been performed on this topic, ranging from a young boy’s ice cream making experiment to those done by college students and physicists. Erasto Mpemba, a young boy in South Africa, discovered that boiled milk frozen without first being cooled made ice cream much faster than milk that had been cooled. Laughed at and confused, he enlisted the help of a visiting professor, Dr. Osbourne, who began a series of controlled experiments to investigate Mpemba’s findings [4].

Dr. Osbourne’s experiments confirmed Mpemba’s results, and he determined that any sample beginning at a temperature greater than 25°C would freeze in less time than water beginning at 25°C [4]. Ian Firth conducted a series of experiments in attempt to reproduce Osbourne and Mpemba’s results and had some similar results [2]. Additionally, Eric Deeson, an instructor at Newman College of Education in Birmingham, had his students replicate the experiments, which produced similar results as well [1]. Seemingly, it is true that hot water freezes faster than cold, but no one has been able to explain this for certain. Our effort is to replicate these results and try to understand and explain the cause.

In our attempt to replicate these experiments, we turn to thermoelectric cooling. Rather than use a large conventional freezer, we chose to use smaller samples with the advantage of being able to watch our experiments without disrupting the system by opening and closing the freezer door. However, to perform our experiments, one needs a little bit of background on thermoelectric cooling.

A thermoelectric cooler is a small device made up of two ceramic plates that act as semiconductors of opposite charge, two leads, one of positive charge and one of negative charge. A current is passed through the plates, creating a cooling effect, as first suggested by Peltier in 1834 [3]. The cooler has two “sides”: a hot side and a cold side. The cold side is up when the red lead is on the right side of the black one (positive right of negative). As the
cold side gets colder, the hot side gets hotter, as the heat from the cold side is being “sucked” through to the hot side. In order to keep the cold side getting colder (for our purposes, to get it to reach 0°C and below) you must disperse as much heat as possible from the hot side. To do this, you will place the hot side on top of a small heat sink and use a fan to cool the heat sink. The more powerful fan and larger heat sink used, the more effectively you will disperse heat, cooling the cool side of the thermoelectric cooler, and the more effectively your experiments will run.

2 Possible Explanations of the Effect

Ian Firth lists several conditions that appear to be very important in creating the effect. They are:

- air circulation around the beaker
- the movement of water within the beaker
- a temperature difference between top and bottom
- evaporation from the top surface [2].

Eric Deeson confirms Firth’s claim that evaporation at the top helps. Deeson states, “the larger the surface area, the more rapid the loss of heat” [1].

3 Safety

There are several safety concerns in this experiment. DO NOT to allow fingers too close to the fan. Also, the heat sink underneath the thermoelectric cooler will get VERY hot, DO NOT touch the heat sink after an experiment, give it ample time to cool down, at least a few minutes, before touching it. Once the power source to the thermoelectric cooler has been turned off after cooling, heat transfers to the cooler quickly, be careful not to burn fingers.

4 The Experiment

This experiment requires the use of the following materials:

- Thermoelectric cooler, at least 1-1/4 x 1-1/4 inches
- Heat sink
- Large power source (capable of 5A)
- Small power source (capable of 3A)
- Fan (DC power) 3 x 3 inches (approx.)
- Thermocouples and temperature reader
• High thermal conductivity paste
• Styrofoam insulation
• Water
• Vessel for containing water during freezing.

4.1 Procedure

4.1.1 Preparing the Cooler for Use

1. Place fan bottom-side down on a surface unaffected by intense heat.
2. Attach black clip to black fan wire and red to red fan wire. Attach the other ends of these clips to the small power source’s output sockets.
3. Stack heat sink on top of fan.
4. Apply thermal conductivity paste to bottom of thermoelectric cooler (red wire on the right means top up) and press down onto center of heat sink gently and evenly.
5. Put thermal conductivity paste on the bottom of a 5mL crucible and place it into the center of the thermoelectric cooler.
6. Place styrofoam insulation over setup carefully, with open-side down over the heat sink and the small open square-side allowing only the thermoelectric cooler to be seen.
7. Pull wires up through the slits in the styrofoam gently so that they are sticking straight out from the cooler.
8. Put a thermocouple through the hole in the center of a piece of Lexan and make sure that when it is placed over the top of the setup, the thermocouple reaches almost to the bottom of the crucible. We want the thermocouple to read temperature at the center of the 1mL sample we will be using.

4.1.2 Experimental Procedure

• Put 1mL water at 25°C into the crucible using the 5mL syringe.
• Turn on the power source for the fan.
• Start the stopwatch and turn on the power source for the thermoelectric cooler simultaneously.
• When the thermocouple inside the crucible reads 0.0°C, stop the stopwatch and record the time.
• Repeat this procedure nine times. Repeat this procedure at higher temperatures: 40°C, 50°C, 60°C, 70°C, and any higher temperatures that the equipment will allow.
Figure 1: Thermoelectric cooler setup with no styrofoam insulation

Figure 2: Setup with insulation
4.2 Results

From this initial experiment, our results are quite different from what we expected to find. Freezing times appear to increase linearly, as shown in Figure 3.

These results are quite different from those reported by Osbourne and Mpemba, shown in Figure 4. Their curve clearly indicates a significant decrease in freezing time as temperature increases [4].

Additionally, experiments by Latonia Polk of the Food Science department at the University of Delaware with an ice cream maker showed a similar freezing curve to that of Osbourne and Mpemba, however the peak freezing time occurred at a higher temperature. Her results are shown in Figure 5.

It seems that our experiment, the only one in which a thermoelectric cooler was used, is the only one that is not seeing the effect in some form. We speculate that this is because the thermoelectric cooler cools by conduction through the bottom of the crucible and does not allow for convection currents inside the specimen or in the atmosphere around it as would a larger beaker of water in a conventional freezer. Though we are not seeing the effect, our results may be significant because they show that bottom cooling does not produce the effect, possibly confirming Firth and Deeson’s ideas that side and top cooling are very important in producing the effect [1, 2].
Figure 4: Osbourne and Mpemba’s results from freezing 70mL of water in a 100mL beaker

Figure 5: Food Science student Latonia Polk’s results for water in an ice cream maker
5 Other Experiments We Have Tried

In addition to the experiment described above, we have also tried several others that were not effective in reproducing the results of others:

- Try surrounding the crucible in styrofoam. Set up a thermoelectric cooler as usual and invert it so that the crucible is cooled from the top.
- Try using more water in the previous setup—3mL rather than just 1mL—to reduce the amount of air the thermoelectric cooler must cool before it begins to cool the water.
- Try using the first setup with an additional thermoelectric cooler on the bottom to help cool the water faster.
- Implant a test tube in a sheet of styrofoam so that the sides are covered but the bottom and top are exposed. Heat sink and thermoelectric cooler are set up as usual, place the bottom of the test tube onto the thermoelectric cooler with lots of paste to enhance conductivity. Set up a small fan to blow air across the top of the test tube to create a dry atmosphere and encourage evaporation.

6 Other Suggestions for Further Research

- One suggestion from Food Science is to determine how additives like sugar and salt affect freezing times.
- Try your experiments with a thin layer of oil covering the top of the water to determine if the effect still occurs and whether or not freezing time is increased.

References