Lava Cake Lab: Heat Transfer Analysis

David Bui, Joshua Paul, Robert Huang, Arun Kamath

October 7, 2024

Introduction

The purpose of this experiment is to analyze the baking process of lava cakes, focusing on heat transfer mechanisms relevant to different parts of the dessert. By applying principles of conductive, convective, and radiative heat transfer, this study aims to investigate how heat flows through the cake's outer layers while maintaining a molten center. This experiment identifies optimal cooking times and temperature settings to achieve the desired consistency for both the baked exterior and the liquid core.

The experimental setup includes an electric oven with manual temperature controls, a thermometer for monitoring the internal temperature, and various time intervals for assessing how heat transfer affects the cake's structure.

Materials

- Kitchen Oven
- Bitter Dark Chocolate Chocolate
- Unsalted Butter
- Granulated Sugar
- Eggs
- Food Scale
- Water
- Kosher Salt
- All-purpose Flour
- Vanilla Extract
- Oven-safe Dishware/Glassware
- Measuring Cups
- Whisk

Device Calibration

To ensure uniform baking conditions for multiple lava cakes baked simultaneously, we assess the uniformity of the kitchen oven. Although we assume the oven's interior functions as a thermal system with a constant internal temperature, we must verify this assumption. After preheating the oven, containers of water are placed at various locations (front and back, left and right, top and bottom), and their temperatures are measured after several minutes.

(a) Calibration Setup

(b) Oven Calibration Setup and Temperature Measurement

Figure 1: Oven Calibration and Setup.

(a) Ingredients Setup

(b) Oven Calibration Setup and Temperature Measurement

Figure 2: Oven Calibration and Setup.

Procedure

1. Preheat the oven to 425°F.
2. In a mixing bowl, gently melt 100 grams of chocolate along with 100 grams of butter.
3. In another bowl, beat together 2 eggs, 2 egg yolks, and 50 grams of sugar until the mixture turns pale

Table 1: Oven Calibration Water Temperatures

Location	Temperature (5 min)	Temperature (10 min)	Temp. Change
Top, Front, Left	139°F	180°F	41°F
Top, Rear, Right	178°F	198°F	20°F
Bottom Center	171°F	207°F	36°F
Top Center	162°F	196°F	33°F

and thickens slightly.

4. Gradually pour the melted chocolate and butter into the egg mixture, stirring carefully to ensure the ingredients are evenly distributed.
5. Add 30 grams of flour to the mixture, folding it in until fully integrated and smooth.
6. Lightly grease the ramekins, then pour the batter evenly into each.
7. Bake the cakes in the oven for 12–14 minutes, making sure the heat solidifies the outer layer while keeping the center liquid.
8. Use both a thermometer and visual inspection to check the cakes. The edges should be firm, with the center remaining soft and molten.
9. Once done, take the cakes out of the oven and allow them to cool for about 2 minutes before serving.

Predictions

We predict that the covered cake will heat up less quickly, and so the "lava" will be more viscous throughout the cake. This is because when we cover the ramekin, we are preventing convective heat transfer from the air to the cake, which reduces a mode of heat transfer. If we observe a gradient in hardness (i.e. hard on the outside, soft on the inside), that implies conduction is dominating because the temperature is highest at the cake boundary and diffuses inwards. If the cooking time is increased, we would expect the heat to fully distribute within the cake and become uniform in texture.

Figure 3: Mixing Ingredients for Lava Cake Batter.

Figure 4: Lava Cakes in Oven During Baking Process.

System Identification

Heat Transfer Mechanisms

This experiment involves multiple forms of heat transfer, each relevant to the structure of the lava cake:

- **Conduction:** Heat transfer from the oven walls to the ramekin and from the ramekin to the batter, solidifying the outer layers of the cake.
- **Convection:** Hot air circulating in the oven, allowing for even cooking of the cake's surface.
- **Radiation:** Radiant heat from the oven's heating elements transferring energy to the batter to ensure a firm crust forms on the surface.

Convection will be limited if we cover the cakes while heat is being supplied. In that case, only conduction and radiation will be important.

Input

The primary input involves controlling the oven temperature and baking time to ensure heat transfer is appropriate for achieving a balance between a solid outer cake layer and a molten core. Oven preheating

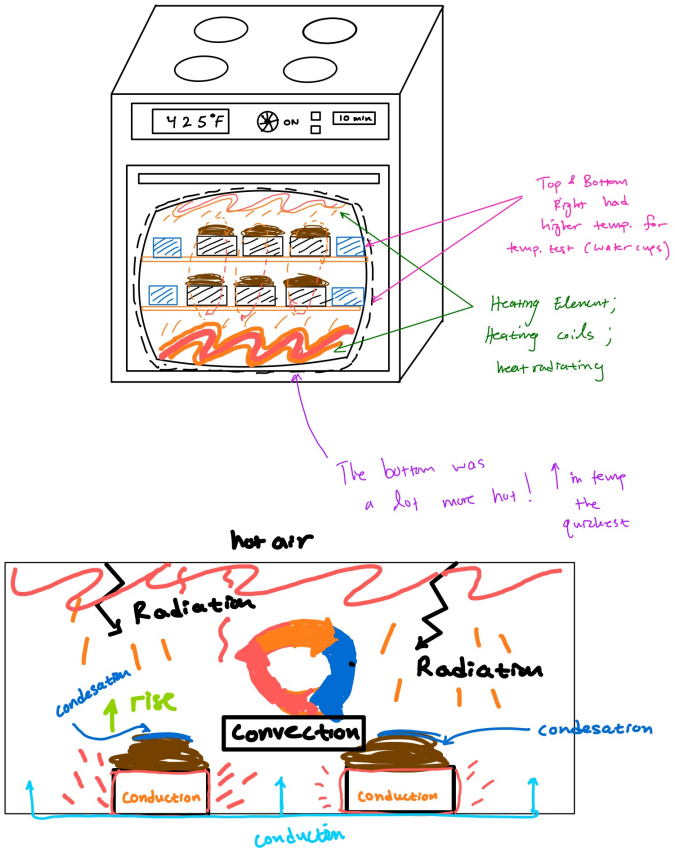

Figure 5: Diagram Showing Heat Transfer Mechanisms in Lava Cake Baking.

and consistent temperature management are essential to this process.

Outputs

- **Exterior:** Firm, baked crust formed through conductive and convective heat transfer.
- **Interior:** Soft, molten center achieved by limiting the time for conductive heat to fully penetrate the cake.

Discussion Results

From the pictures, we notice that the covered cakes were darker on top, and the chocolate inside oozed. The cakes that were covered had minimal liquid and seemed cooked all the way through. Our finished lava cakes are depicted in Figure 6. The two lava cakes at the top were covered and baked for 7 min. The two lava cakes in the middle were uncovered and baked for 9 min. The two lava cakes at the bottom were uncovered and baked for 9 min. There was no difference in taste between these cakes, but we experienced significant differences in texture.

Figure 6: Final Lava Cake After Baking. Notice the molten interior and firm crust.

Conclusion

This lab demonstrates how precise control over multi-relevant heat transfer mechanisms—conductive, convective, and radiative—is crucial to achieving the perfect balance of a firm outer crust and molten interior in lava cakes. Through proper temperature control and monitoring, optimal baking conditions can be achieved, providing consistent results.The only lava cakes that remained liquid inside were those that were covered and baked for 7 min. The uncovered lava cakes baked for 7 min and 9 min did not have any liquid chocolate on the inside. This suggests that the covered lava cakes did not receive as much heat transfer as the lava cakes that were uncovered (i.e., the cover limited heat diffusion through the lava cake such that the characteristic length of heat diffusion was reduced), and the lava cakes were thus able to retain their molten interior. Moreover, the uncovered lava cakes baked for 9 min were significantly drier than the uncovered lava cakes baked for 7 min, which stayed moist despite not having melted chocolate on the inside. This result corroborates the time dependence of the diffusion equation (i.e., time is proportional to the characteristic length of heat diffusion).

Figure 7: All of us Together