Reference [1]

Sun Toasted Marshmallows

At what distance from the sun will the solar heat cook your marshmallow to the perfect brownness

MANCHESTER 1824
The University of Manchester

Group 5: Ella Barnes Harley Brobbin Colin Dickey Mattias Evans Martyna Jarocka Seungyeon Lee

ABSTRACT

Through testing, marshmallows were found to melt at around 43C and brown at around 60C. A computer program was made to simulate the marshmallow being heated up by the sun and the time taken at different distances was found.

INTRODUCTION

The aim of this experiment was to use the sun's solar power to melt a marshmallow. The experiment focuses on at what temperature the marshmallow burns and caramelises, which can be used to calculate at what distance the marshmallow has to be placed at from the sun.

Marshmallows consist of a mixture of sugar, corn syrup, and gelatin. The gelatin is used as a whipping agent that allows the mixture to be whipped up into a foam [2].

ASSUMPTIONS

The following assumptions have been made;

- the marshmallow will not expand when heated
- the marshmallow is cylindrical
  - radius R, length l
- the incoming radiation is distributed evenly on the curved surface
- the radiation from the sun is assumed to be a blackbody radiation

THEORY

The main factors of melting the marshmallow that we considered was the caramelization of the outside as well as the middle of the marshmallow becoming gooey. The marshmallow biomes gooey in the middle due to gelatin melting, gelatins melting point is at 35℃ [3] so to achieve that we modelled the time required to melt the marshmallow such that the middle reaches a temperature of 45℃. The browning of the marshmallow occurs due to the sugars caramelising, the caramelization process starts at 150℃ and starts to burn above 200℃ [4]. For this project we picked 4 different temperatures between the sugars starting to caramelise and burning to model the different amount of toasted that people prefer.

There are three contributions to the temperature and temperature distribution of a body in space: radiation absorption, emission and thermal conduction within the body. The power, $\dot{Q}$ absorbed by a cross section of area A at a distance d from the sun is

$$\dot{Q} = \frac{(1-\alpha)AL}{4\pi d^2},$$

where A is the rectangular cross section of the marshmallow (2Rl), d is the distance from the sun, L is the luminosity of the sun and α is the albedo of the marshmallow. As the cylinder is divided into blocks, only the curved surface blocks will absorb radiation, while all surface blocks emit radiation leading to following temperature contributions:

$$1)\ \dot{T}_{curved\ shell\ block} = \frac{(1-\alpha)RlL}{2\pi d^2 C_{block} N}$$

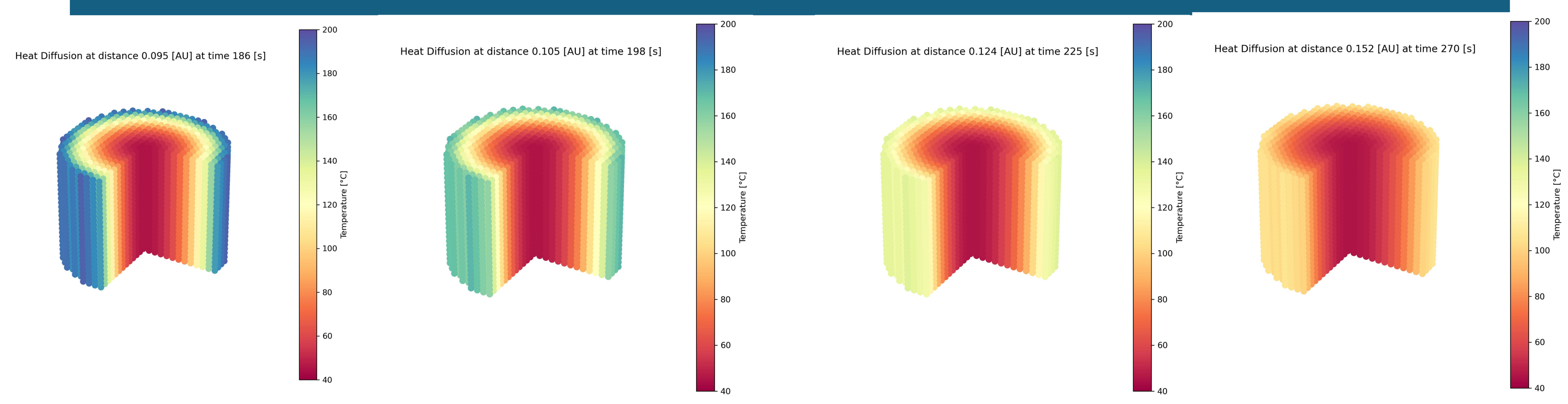
$$2)\ \dot{T}_{emission} = -\frac{\epsilon\sigma T_{block}^4}{C_{block}},$$

where ϵ is emissivity and C is heat capacity.

METHODOLOGY

Finite Difference Method:
Cylinder grid of blocks initialised with coordinates, temperature and dT. Every frame the temperature of the blocks is compared to its neighbours summing the differences then scaling dT to change rate of diffusion. Curved surface blocks uniquely increase in temperature per frame by a constant derived from radiation absorption and all surfaces decrease in temperature proportional to T^4. Constants of proportionality calculated in theory.

RESULTS



The set constraint of the middle of the marshmallow reaching 45℃, the marshmallow was placed at different distances from the sun to model different amounts of toast. The chosen distances are; 0.095, 0.105, 0.124, and 0.152 AU. These distances were chosen to provide a different toast on the outside based on the fact that by the time the boundary condition for the middle of the marshmallow is met the outside would reach a different temperature due to the radiation.

The plots above show that when the marshmallow is at 0.095AU, the temperature of the outside reaches around 190℃.

DISCUSSION

CONCLUSIONS

REFERENCES

[1] astronaut png PNG Designed By from https://pngtree.com/freepng/astronaut-and-sun-png-vector-design_6454896.html?sol=downref&id=bef
[2] Christian, Elizabeth; Vaclavik, Vickie (1996). *Essentials of Food Science*. New York, NY: Marcel Dekker. page 271
[3] Igoe, R.S. (1983). *Dictionary of Food Ingredients*. New York: Van Nostrand Reinhold.
[4]Harold McGee. "On Food and Cooking", 2nd Edition (2004), Scribner, New York, NY. "Sugar, Chocolate and Confectionery", Page 656.

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ABSTRACT

This study investigates the use of solar radiation to optimally roast marshmallows, achieving an internally melted gelatin centre and externally caramelized sugars. Computational modelling was employed to simulate marshmallow heating at various solar distances (0.095–0.152 AU), identifying a distance range (~0.105–0.124 AU) that balances ideal internal softness and external browning without burning.

INTRODUCTION

Marshmallows, primarily composed of sugar, corn syrup, and gelatin, have distinctive thermal properties. Gelatin melts at around 35℃, and sugars caramelize externally at significantly higher temperatures [2].

By computationally simulating marshmallow heating at various distances from the Sun, we aim to identify conditions that achieve ideal texture and appearance, bridging concepts from thermal physics and food science.

ASSUMPTIONS

- Cylindrical marshmallow (radius R, length l) with no shape change due to expansion or melting
- Even distribution of incident radiation on the curved surface, ignoring top/bottom faces
- No additional mass or moisture loss is considered
- Thermal properties unchanged

THEORY

The main factors of melting the marshmallow that we considered were the caramelization of the outside and middle of the marshmallow becoming gooey.

- Gelatin melting (35℃): The internal gelatin of the marshmallow begins to melt around 35 ℃, giving it a soft, gooey texture [3].
- Maillard Reaction (>120℃): Amino acids reduce to simple sugars [4].
- Caramelisation (150-180℃): Sugar bonds break and react with each other, changing the flavour and colour [5].
- Carbonisation (>180℃): If the temperature exceeds 180℃, the sugar produces carbon, giving a bitter and charred taste [6].

We modelled the time required to melt the marshmallow such that the middle reaches a temperature of 45℃ (a gooey texture).

There are three contributions to the temperature and temperature distribution of a body in space: radiation absorption, emission and thermal conduction within the body. The power, $\dot{Q}$ absorbed by a cross section of area $\mathbf{A}$ at a distance d from the sun is

$$\dot{\mathbf{Q}} = \frac{(\mathbf{1}-\alpha)\mathbf{AL}}{\mathbf{4\pi d^2}}$$

where $\mathbf{A}$ is the rectangular cross section of the marshmallow ($2Rl$), *d* is the distance from the sun, $\mathbf{L}$ is the luminosity of the sun and α is the albedo of the marshmallow. The radiative properties of a marshmallow behave like matte white paper, which has an albedo of 0.3 [7]. As the cylinder is divided into blocks, only the curved surface blocks will absorb radiation, while all surface blocks emit radiation leading to following temperature contributions:

$$1)\ \dot{\mathbf{T}}_{\textbf{curved shell block}} = \frac{(\mathbf{1}-\alpha)\mathbf{RlL}}{\mathbf{2\pi d^2 C_{block} N}}$$

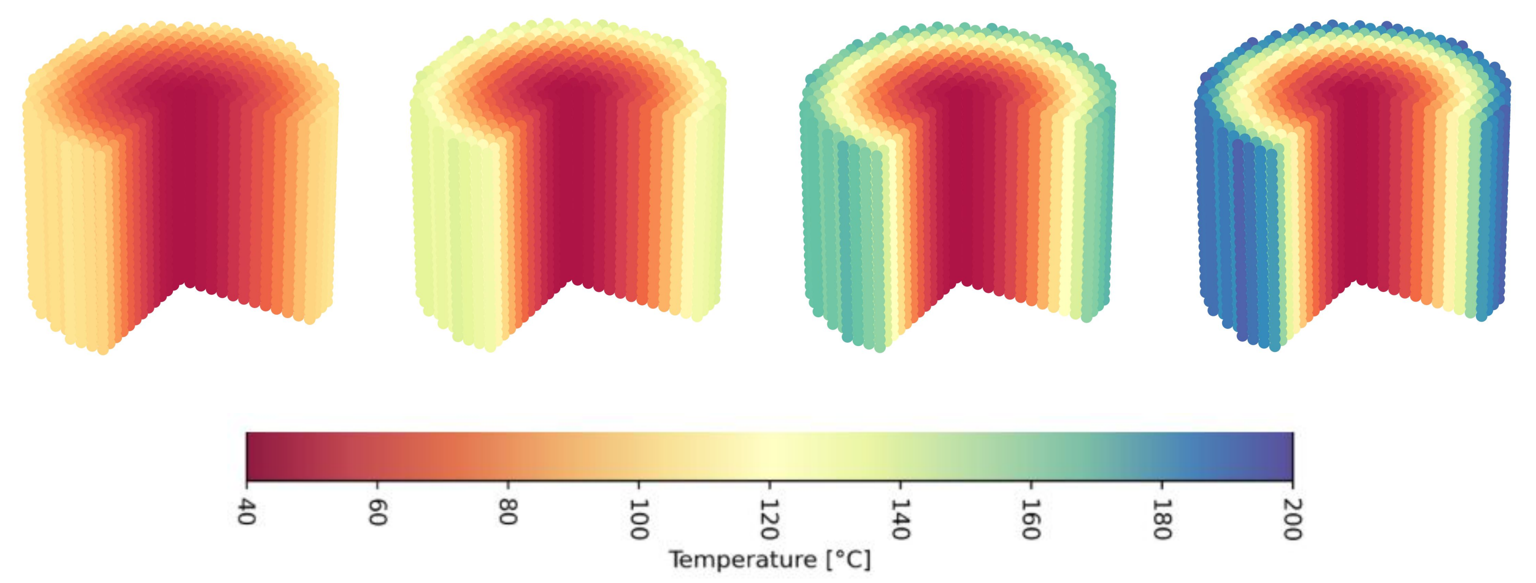
$$2)\ \dot{\mathbf{T}}_{\textbf{emission}} = -\frac{\epsilon\sigma\mathbf{T_{block}}^4}{\mathbf{C_{block}}}$$

where ϵ is emissivity and $\mathbf{C}_{\text{block}}$ is heat capacity. If again we use the properties of paper, we find ϵ = 0.95 [8].

METHODOLOGY

- The marshmallow was modelled as a cylinder with radius (R) and length (l), discretized into uniform grid blocks. Each block had dimensions approximately (Δr) in the radial direction and (Δz) along the axis. We employed the Finite Difference Method to simulate heat diffusion, initializing all blocks with an initial uniform temperature of ($\mathbf{T}_{\text{initial}}$).
- At each simulation step (Δt), we calculated temperature changes based on heat conduction between adjacent blocks, scaled by the thermal conductivity (k) and the heat capacity of each block ($\mathbf{C}_{\text{block}}$). Curved surface blocks absorbed solar radiation proportional to the solar luminosity ($\mathbf{L}$), marshmallow albedo (α), and inversely proportional to the square of the distance from the sun (d^2). All surface blocks emitted thermal radiation proportional to their emissivity (ϵ) and temperature raised to the fourth power ($\mathbf{T}^4$).
- Simulations continued until the center of the marshmallow reached the specified temperature of 45°C. Validation of the model was done by comparing simulated temperature distributions with experimentally measured melting and browning temperatures.

RESULT



Simulations conducted at 0.152 AU, 0.124 AU, 0.105 AU, 0.095 AU showed varied surface toasting:

- 0.152 AU, 4m 30s, 110°C: No browning.
- 0.124 AU, 3m 45s, 125°C: Maillard, light browning.
- 0.105 AU, 3m 18s, 165°C: Caramelisation, medium browning.
- 0.095 AU, 3m 06s, 195°C: Carbonising, blackened.

Radial temperature profiles confirmed increased temperatures towards the surface, highlighting the impact of distance on toasting intensity.

DISCUSSION

The temperature gradients observed in the simulations result from the radiative heating mechanism, where the external surface heats significantly faster than the internal structure due to the direct absorption of radiation. This aligns well with established thermal behaviour, where gelatine melting (~35°C) occurs at significantly lower temperatures than sugar caramelization (~160°C).

The current model, however, employs simplifying assumptions such as uniform heat distribution, cylindrical geometry without expansion, and ignores other heat-transfer processes like convection or complex radiation interactions in real space environments. These simplifications limit the real-world applicability of our results.

Future improvements, including the incorporation of non-uniform heating conditions, thermal expansion, and more accurate radiation and convection modelling, would enhance the predictive capability and broaden potential applications in thermal physics and food science contexts.

CONCLUSIONS

This investigation explored the use of solar radiation for achieving simultaneous gelatine melting and sugar caramelization in marshmallows, identifying an optimal distance range (~0.105–0.124 AU) to balance internal softness and external browning. While simplified assumptions constraints direct real-world application, the study illustrates a novel integration of thermal physics and food science. Future research could extend this methodology to other foods and incorporate more comprehensive heat-transfer mechanisms.

[1] astronaut png PNG Designed By from https://pngtree.com/freepng/astronaut-and-sun-png-vector-design_6454896.html?sol=downref&id=bef date accessed 04/04/2025
[2] Christian, Elizabeth; Vaclavik, Vickie (1996). *Essentials of Food Science*. New York, NY: Marcel Dekker. page 271
[3] Igoe, R.S. (1983). *Dictionary of Food Ingredients.* New York: Van Nostrand Reinhold.
[4]Harold McGee. "On Food and Cooking", 2nd Edition (2004), Scribner, New York, NY. "Sugar, Chocolate and Confectionery", Page 656.
[5] https://www.theverge.com/2017/6/11/15774634/marshmallows-smores-camping-camp-fire-summer-food-science date accessed 04/04/2025
[6] Setianingsih, Tutik & Kartini, Indriana & Arryanto, Yateman. (2014). The Effect of Caramelization and Carbonization Temperatures toward Structural Properties of Mesoporous Carbon from Fructose with Zinc Borosilicate Activator. Indonesian Journal of Chemistry. 14: 253-261. 10.22146/ijc.21236.
[7]Gilchrist, G. (2011). A simple method to determine surface albedo using digital photography. *Physics Education*, 46(5)
[8]TABLE OF EMISSIVITY OF VARIOUS SURFACES, https://www.transmetra.ch/images/transmetra_pdf/publikationen_literatur/pyrometrie-thermografie/emissivity_table.pdf, date accessed 04/04/2025