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P5 5 Thermal Properties of the Gregg's Steak Bake

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Abstract

In this paper we investigate the thermal properties of a Gregg's Steak Bake to determine if it is truly a thermodynamic mystery. Using Newton's law of cooling as a model for this object's temperature change, we have calculated its thermal time constant, $\tau = 1733.5s \pm 5.4s$. Thus we have found an optimal window for consumption which lasts only $309.0s \pm 1.0s$. To simplify the model, we have assumed a uniform internal temperature and that convectional heat loss dominates.

Introduction

The thermal properties of the Gregg's steak bake (GSB) have remained a point of contention among consumers. Observations suggest that the GSB either exists at an uncomfortably high or low temperature with little evidence in between. Thus, our investigation aims to show that it can be accurately modelled using Newton's law of cooling in order to determine the optimal window for consumption between the extremes which are most frequently found.

Newton's law of cooling states that an object's temperature decays exponentially towards that of its surroundings and proportionally to its surface area [1]. This assumes that the surrounding air temperature remains constant, with a small temperature difference between the body and its surrounding gas [2] decreasing over time.

Method

The surface area of the GSB is difficult to precisely calculate due to its ridged pattern which is used to differentiate it from other baked products. To avoid this issue, we can derive an equation from the rate of heat loss which incorporates several unknown quantities into the thermal time constant:

$$-C\frac{\partial T}{\partial t} = hA(T - T_{air}), \tag{1}$$

The terms h, A and C denote the heat transfer coefficient, surface area and heat capacity respectively [1]. All of these constants are difficult to calculate directly for a steak bake so the following derivation details how they are combined into τ.

The ambient temperature, T_{air}, remains constant at $19°C$ over the time interval $t = 0$ to $t = t$. However, the internal temperature of the GSB decays exponentially from T_0 to $T(t)$ during this period.

We show this relationship by rearranging Eq (1) and integrating both sides over the full ranges of temperature and time respectively.

$$\int_{T_0}^{T_t} \frac{dT'}{T' - T_{air}} = -\frac{hA}{C}\int_0^t dt'. \tag{2}$$

After completing this integration and applying the laws of logarithms the equation reads:

$$\ln \frac{T_t - T_{air}}{T_0 - T_{air}} = -\frac{t}{\tau}, \tag{3}$$

where $\tau = \frac{C}{hA}$ is the thermal time constant. Finally, by exponentiating and rearranging this equation, we produce an exponential temperature decay function synonymous with Newton's law of cooling.

$$T(t) = T_{air} + (T_0 - T_{air})e^{-t/\tau}. \tag{4}$$

Eq (3) and Eq (4) allow us to calculate the thermal time constant when paired with measurements of the steak bake's temperature at discrete time intervals over the course of its cooling.

Once fully cooked, the GSB's internal temperature was recorded at 2 minute intervals using a standard catering probe thermometer, accurate to within $0.1°C$. The thermometer was inserted into the center of the steak bake for maximum precision. The display counter was temperature controlled throughout, $T_{air} = 19.0°C$ and the initial temperature was recorded at $T_0 = 90.1°C$. Therefore, Eq (3) can be rearranged to plot a linearised version of the data and determine the value of τ.

Results

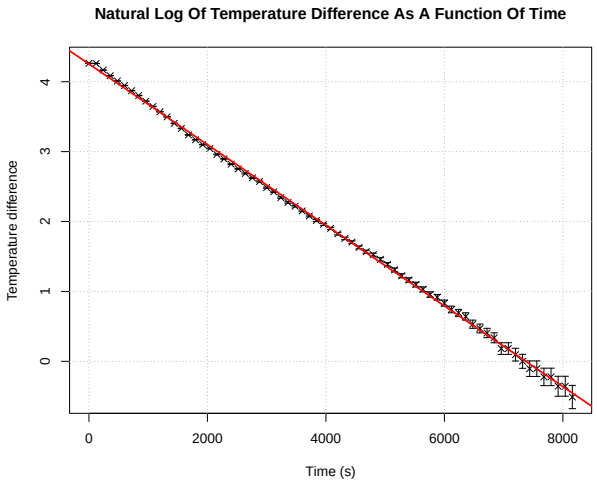

Figure 1: A graph showing the natural log of the difference in temperature between the steak bake and the surrounding air as a function of time.

Using Eq (3), we plotted the data and performed a linear regression to determine the gradient. Hence, $\tau = 1733.5 \pm 5.4s$ or 28.9 ± 0.1 minutes. Substituting this value into Eq (4) allowed us to display Newton's law of cooling for the system and indicate more clearly the timescale of temperature decay.

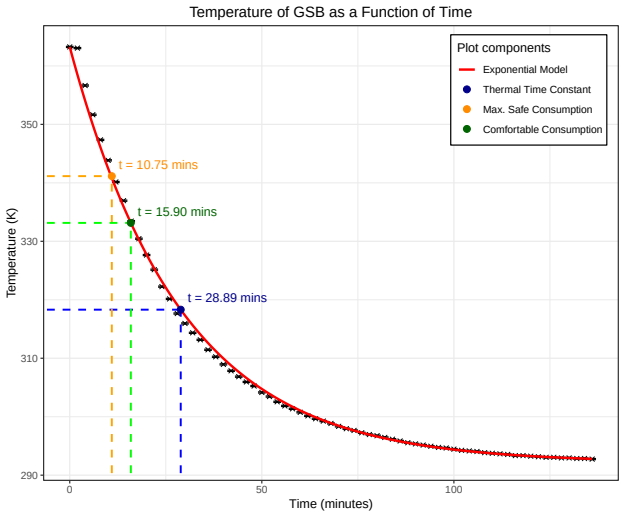

Figure 2: The exponential model based on the value of τ calculated from the previous figure. This overlays the raw experimental data.

The figure above clearly shows that the optimal window for consumption lies between 10.75 and 15.90 minutes. This range is defined by the safe maximum serving temperature for hot food ($68°C$) [3] and the preferred safe minimum temperature for consumption of hot beverages ($60°C$)[4]. Thus, this window lasts 5.15 ± 0.02 minutes.

Conclusion

While Newton's law of cooling is a simplified model, it accurately predicts the temperature decay of the Gregg's steak bake under these conditions. The short thermal time constant partially explains how the GSB is often consumed in either a scalding or tepid state. Despite contention around the safe temperature for consumption [5], we suggest consuming this product within the 5.15 minute window displayed in Figure 2.

References

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