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P5_3 Prince Pondicherry and the Chocolate Palace

M. E. Evershed, T. J. Beedle, E. J. Baldwin, N. E. Cook

Department of Physics and Astronomy, University of Leicester, Leicester, LE1 7RH

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Abstract

Prince Pondicherry of India, from the book Charlie and the Chocolate Factory [1], ordered a huge palace to be created for him made entirely out of chocolate, but soon after it was completed the entire palace melted around him due to the heat of the sun. We calculated that during May when the sun over India is hottest, the palace would have reached its melting point by 12:00, a little more than 6 hours after sunrise, but it would take approximately two days to melt entirely.

Introduction

In the 1964 book Charlie and the Chocolate Factory [1], Prince Pondicherry asks Willy Wonka to construct a palace made entirely of chocolate. The Prince planned to live in it, but shortly after completion the entire palace melts due to the sun's heat. We calculated how long this would take to melt, assuming that the palace was built near Goa in India and that it melted on a hot day in May [2].

Theory and Results

To calculate the amount of time it would take for the palace to melt, we first worked out how much chocolate was used in construction. The palace is described as having 100 rooms [1], so we created a model in which each room is the size of an average living room (5 m x 6 m x 3 m) [3], arranged on 2 floors of 50 rooms each. We assumed the ceiling and floor could be modelled as walls, and used the width of a standard brick (10 cm) [4] for the wall widths. We found that the total volume of chocolate in each room would be 12.6 m^3 and the total volume in the palace would be 1260 m^3. We take the density of chocolate as 1325 kgm^{-3} [5], so the mass of chocolate used in the palace is 1.67×10^6 kg.

The total energy required to melt the palace was found using equations to calculate, firstly, the energy to raise the temperature to the melting point (1) and secondly, the energy for the phase change (2). Equation (1) is shown below:

$$Q_c = mc\Delta T, \tag{1}$$

where Q_c is the energy required to bring the palace to melting temperature, m is mass, c is the specific heat capacity of the chocolate, and ΔT is the temperature change necessary to cause the chocolate to melt. The specific heat capacity of chocolate is 1295.352 $Jkg^{-1}K^{-1}$ [6] and the temperature at which chocolate melts is 36 ^{o}C or 309.15 K [7]. The temperature at the start of the day is 28 ^{o}C or 301.15 K [8] so the temperature difference required is 8 K. Combining these with the mass previously calculated and using Equation (1), we found the energy required to reach the melting point, Q_c, is 1.73×10^{10} J. We then used Equation (2) to calculate the energy required to change the phase of the chocolate, using the latent heat of chocolate of 45 Jg^{-1} [9].

$$Q_L = mL, \tag{2}$$

where Q_L is the energy required to change the phase of the chocolate, m is the mass of the chocolate, and L is the latent heat of the chocolate. We found the value of Q_L to be 7.51×10^{10} J. We will use Q_c and Q_L separately, in order to obtain a value for the start time for the melting of the palace, as well as the total time taken for complete melting.

We have assumed that the only heat transfer affecting the palace is the solar energy directly incident on the roof of the palace which, using our model stated earlier, is 1500 m^2. Using this area and the previous energies required, the energy per metre squared can be found for the temperature change and the phase change: 1.153×10^4 kJm^{-2} and 5.007×10^4 kJm^{-2} respectively. We created a graph to show the maximum hourly solar radiation in the Goa region [2] which is shown in Figure 1.

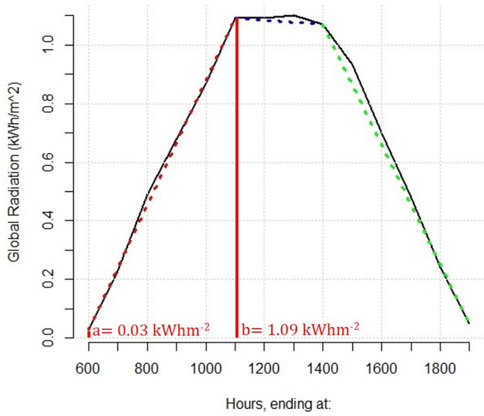

Figure 1: Maximum values of Solar Radiation during May in Goa, India [2].

The three dotted lines in Figure 1 were used to approximate the solar radiation over the day. First we found the area under the first section of the graph (red line) to see whether the total energy over this time would be enough to heat the palace to its melting point. This was found to be 1.008×10^4 kJm^{-2} using the formula for the area of a trapezium:

$$A = ((a + b)/2) \times h, \tag{3}$$

where A is the area, a and b are the lengths of the top and bottom of the trapezium respectively, and h is height (Note: The trapezium is on its side). This is not enough energy on its own, and the remaining energy necessary was found to be 1.45×10^3 kJm^{-2}. We found the equation for the blue line and integrated it in order to find the time that the palace would be at 36 ^{o}C and begin to melt. This is 12:00, midday.

We then calculated all sections of the graph separately, in order to find the total flux of solar energy over the whole day. This was found to be 3.18×10^7 Jm^{-2}, but the total energy required to bring the whole mass of the palace to a liquid is $Q_c + Q_L$: 6.16×10^7 Jm^{-2}. Therefore, we conclude that it would take around two days for the palace to be entirely liquid.

Discussion and Conclusion

During the analysis, we used a simple model. Many of the rooms would be larger or smaller, but the amount of chocolate used would be about the same. Also, we considered the energy lost due to cooling overnight to be negligible.

We found that although the palace reaches the melting temperature of chocolate at 12:00 on the first day after construction, using solar radiation alone, it would take around two days to completely melt.

References

[1] Roald Dahl, *Charlie and the Chocolate Factory*, 1964, p. 25-26

[2] `http://wgbis.ces.iisc.ernet.in/energy/paper/prospects_of_solar_energy/analysis.htm`[Accessed 11 October 2017]

[3] `http://www2.d125.org/im/ACAD/pdf/room_sizes.pdf`[Accessed 11 October 2017]

[4] `http://www.novabrick.co.za/clay-brick-sizes` [Accessed 11 October 2017]

[5] `https://goo.gl/bxJ93c` [Accessed 11 October 2017]

[6] Ferenc A. Mohos, *Confectionery and Chocolate Engineering: Principles and Applications*, Table 3.11

[7] `http://www.food-info.net/uk/qa/qa-fp45.htm` [Accessed 11 October 2017]

[8] `http://www.holiday-weather.com/goa/averages/may/` [Accessed 11 October 2017]

[9] S. Beckett, *The Science of Chocolate*, 2000