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P1_4 Ice Ice, Benny.

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Abstract

In this paper, we investigated the time taken for the famous London landmark the Elizabeth Tower, more commonly known as Big Ben, to melt if it was completely made out of ice. By modelling Big Ben as a perfect cuboid and using equations that define specific latent heat and specific heat capacity we found that it would take 560 days (2 s.f) for an ice structure the size of Big Ben to melt. We believe that this is a reasonable estimation, since it is such a large structure.

Introduction

The Ice Festival held in Moscow in 2018 [1] featured ice sculptures of some of the world's most famous landmarks, including the Trevi Fountain in Rome to the Taj Mahal in India. We have used this festival as inspiration for our proposed study of finding out how long an ice structure the size of Big Ben would take to melt. We have modelled Big Ben as a perfect cuboid that is made out of ice that is solid throughout and has uniform density. The ice contains no impurities and is melted at room temperature and pressure. In this study, the ice structure will be melted by the power of the Sun and we have assumed the sculpture will be have 12 hours of direct sunlight a day.

Theory

To melt ice, it must change state from a solid to liquid. When the temperature of ice is raised from 0°C, the internal energy of the ice increases. This causes the ice's regular molecular structure to break down, resulting in water. Water has a much more randomised internal structure and the particles have a greater amount of energy compared to the particles in ice.

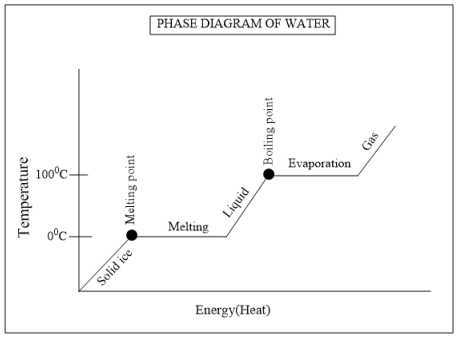

Figure 1: Graph showing energy against temperature for the changing states of water [2].

The change in state from a solid to a liquid can't progress without external energy being applied, so energy from the surroundings must be taken in by the ice. The internal energy is then used to break the bonds in the ice, and will begin to gradually increase in temperature, as shown in Figure 1. For this paper, we are only concerned about the phase change from solid to liquid, so the gaseous stage can be ignored. For our calcu-

lations, we applied the specific latent heat equation (1) and related it to the energy equation (2). These are:

$$Q = mc\Delta T + mL \tag{1}$$

where Q is the energy of the system, m is the total mass, c is the specific heat capacity of ice, T is the temperature, and L is the specific latent heat of ice.

$$Q = Pt \tag{2}$$

where P is power of the Sun, and t is time taken for the ice melt. By making equation 1 and 2 equivalent, the time can be calculated.

Combining equations 1 and 2 and rearranging for time yields:

$$t = \frac{mc\Delta T + mL}{P} \tag{3}$$

Method

We found that the power the Earth receives from the Sun is 1,360 Wm^{-2} [3]. Assuming the Sun is directly above the sculpture, and the Earth's atmosphere does not degrade the power reaching the sculpture, there is then a power of 200,000 W (2 s.f) hitting the 12 m by 12 m top of the sculpture [4]. Substituting this power value, the mass of the sculpture (estimated to be 13,000,000 kg using the volume given the following dimensions: height = 98 m (2 s.f), length and width = 12 m (2 s.f), and density of ice [4]), the specific heat capacity and latent heat capacity of ice [5], and change in temperature (20°C) into equation 3 gives a melting time of 24,000,000 s (2 s.f). This is equivalent to 6700 hours (2 s.f) or 280 days (2 s.f).

Analysis of Results

In this study, we found out that the time it would take to melt an ice structure of Big Ben, when bringing the temperature from -20°C to 0°C, the melting point of ice, was 6700 hours (2 s.f) or 280 days (2 s.f). This is assuming direct sunlight for 24 hours a day. When taking into account the day and night cycle and assuming 12 hours of direct sunlight this becomes 560 days (2 s.f). We acknowledge that in any English day the probability of getting 12 hours of direct sunlight is low, and due to this our results are likely an underestimation but not unreasonable given the scale of the structure. However, we have also assumed the sunlight only hits the top of the sculpture and not the sides. A more accurate model for the area hit by sunlight would likely yield a faster melting time because at times the Sun is at an angle to the structure so the sunlight would be hitting a greater surface area of the sculpture.

Conclusion

In this paper we aimed to find the time it would take for the Elizabeth Tower, more commonly known as Big Ben, to melt if it was entirely made from ice. Using the specific heat capacity equation we found that under direct sunlight the tower would take 6700 hours (2 s.f) or 280 days (2 s.f) to melt. Taking into account the day and night cycle of the earth and assuming 12 hours of direct sunlight, increases to 560 days (2 s.f). We felt this conclusion is reasonable given the size of the structure and the assumptions we have made.

References

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