Journal of Physics Special Topics
An undergraduate physics journal

S3_2 The Power Of Ice King

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November 2, 2017

Abstract

We consider how much power it might take for Ice King from *Adventure Time* to freeze a princess by using refrigerator equations. With a refrigerator of coefficient of performance 5.5, it would require 8 MW of power to freeze a female of mass 60 kg and height 1.6 m in a block of ice assuming 100% efficiency. The power required is even higher for lower efficiencies and to freeze a number of princesses in one instant.

Introduction

The animated TV series *Adventure Time* features a character known as Ice King who uses his icy abilities to instantly freeze other characters, powered by his crown. We explore how much power this would take by assuming that Ice King acts as a near-instant freezer. He must do work to reduce the temperature of his target and freeze them in a block of ice. We ignore any energy that would be necessary to shoot water at the target and just focus only on the freezing process.

Figure 1: Ice King's freezing powers in action.

Theory

We model Ice King as a refrigerator with a coefficient of performance (COP) of 5.5 which is the average COP for a fridge according to Tipler [1]. Figure 1 shows Ice King freezing another character in an *Adventure Time* episode. We will assume that Ice King's target is a princess of height 1.6m and mass 60 kg. We estimate the approximate mass of water in the princess's body that will be frozen and combine this with the excess water frozen which will encapsulate the princess and then use refrigerator equations to find the power required to freeze this mass. We rearrange the equation for COP to get the work required in Eq. 1:

$$W = Q_c/COP. \quad (1)$$

The heat removed from the cold reservoir of the freezing princess Q_c is the sum of the energy required to cool the water Q_{cool} and the energy required to freeze the water into ice Q_{freeze}. These are calculated from the following equations:

$$Q_{cool} = mc\Delta T, \quad (2)$$

$$Q_{freeze} = mL. \quad (3)$$

In these equations m is the mass of water, c is the specific heat capacity of water, ΔT is the change in temperature and L is the specific latent heat of water. We evaluate Q_{cool} separately for the ice formed in the body and external ice.

Results

For the mass of water in the princess we use that women's bodies are composed of approximately 55% water [2]. We multiply this by the mass of our princess to get 33 kg of water to be frozen. We find the energy taken to reduce an average body temperature of 37 °C to 0 °C using Eq. 2 where m is 33 kg, c is 4.18 kJ kg^{-1}K $^{-1}$. This gives 5100 kJ as Q_{cool} for just the princess. We approximate the excess mass of ice created by Ice King as equivalent to the mass of the princess (60 kg). The water used to create the excess ice is assumed to be at 15 °C, the temperature of the outdoors, then find that the energy Q_{cool} required to cool this water is 3800 kJ. These energies are added so the total Q_{cool} is 8900 J.

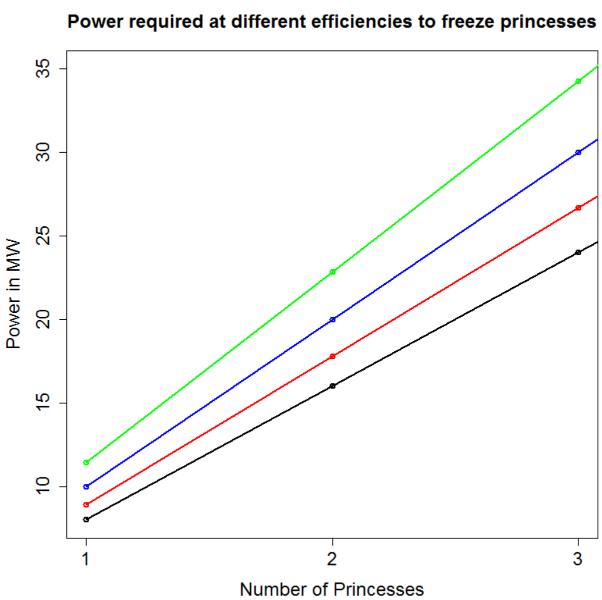

Figure 2: A graph showing the power required to freeze up to 3 princesses using a model of a refrigerator system with efficiencies 70% (green), 80% (blue), 90% (red) and the original 100%.

The energy required to freeze the princess in ice is found using Eq. 3 where the total m is 93 kg and L is 334 kJ kg^{-1}. The freezing energy Q_{freeze} is 31,000 kJ therefore the total energy Q_c is 40,000 kJ. The work W required to freeze a princess is 8,000 kJ using Eq. 1. If Ice King is capable of freezing a princess near-instantaneously, the power required, by dividing the energy by a time of 1 s is 8 MW. It is unlikely that any refrigerator process will be 100% efficient so Figure 2 shows how the power would have to increase for efficiencies less than 100%. We also explore the power required to freeze multiple princesses at the same time. According to Adwen [3], 8 MW is the nominal power for a AD 8-180 wind turbine, so it is very unlikely that this kind of instant freezing would be possible in a real freezer.

Conclusion

The power taken to freeze a princess by *Adventure Time*'s Ice King was investigated and using refrigerator equations in conjunction with the energy for a change of temperature and change of state. The factor of firing water at the princess in order to create ice is neglected and a simple fridge is considered. The power to freeze the average princess in one second is 8 MW, where Ice King is modelled as a fridge with COP 5.5 and 100% efficiency. This value increases to approximately 11.4 MW if Ice King is a fridge with an efficiency of 70%, both of which are similar to the power ratings of wind turbines.

References

[1] Tipler, P (2008). *Physics For Scientists and Engineers*. 6th ed. Basingstoke: W.H. Freeman and Company. p635.

[2] Perlman, H. (2016). *The Water In You.* Available: `https://water.usgs.gov/edu/propertyyou.html`. Last accessed 18th Oct 2017.

[3] Adwen. (2017). *Adwens Prototype 8MW Turbine Dwarfs Bremerhaven Skyline.* Available: `http://www.offshorewind.biz/2017/05/04`. Last accessed 19th Oct 2017.