Journal of Interdisciplinary Science Topics

The Calorific Requirements of a Human Theme Park

Jason Schneider
Honours Integrated Science Program, McMaster University

22/03/2017

Abstract

The purpose of this paper is to examine the amount of calorific energy required to operate a roller coaster small enough to fit inside the human body. It was found that relative to the amount of energy in food, a miniaturized roller coaster initially designed to be fairly large would require little energy at only 9.27×10^{-10} kcal per day.

Introduction

In the television show Rick and Morty, Ruben (a friend of the titular Rick) has a miniaturized theme park built inside of him. This paper seeks to answer the question as to how much power a miniaturized theme park ride would require. Specifically, since the average American over the age of 20 needs anywhere from 2000 to 3000 calories per day [1], what fraction of that energy would be required to operate a miniaturized roller coaster inside of their body?

Methodology

The energy requirements of a miniaturized roller coaster will be calculated using basic Newtonian mechanics. It should be noted that in a frictionless vacuum, this problem would be simpler. Without having to account for friction or air resistance, a roller coaster could simply be pulled up its largest hill then let go freely for the rest of the ride. The theoretical energy requirement can be easily scaled up or down because it is only dependent upon mass and the size of the hill. In order to shrink the power consumption of the coaster, its theoretical power usage will be calculated, then divided by the actual power consumption (given by the manufacturer) to calculate the efficiency. From there, the theoretical energy consumption of the miniaturized version will be calculated, then divided by the efficiency to get an estimate for the actual power consumption of the shrunken down machine.

A problem that arises is how much everything should be shrunken down by. During the Rick and Morty episode *Anatomy Park,* Morty states his age (14), and jumps on a pulmonary alveolus while inside of Ruben's lung. Upon visual examination, Morty appears to be roughly half the height of the alveolus. There is little variation in the volume of the human alveolus [2], which averages $4.2\times10^{6}\ \mu m^{3}$. Approximating the alveolus as a sphere gives it a diameter of 200.2μm. Half of that value is 100.1μm, therefore his height after being shrunken down was approximately 100.1μm. The average height of a 14-year-old American boy is approximately 170cm [3]. 170cm, or 1.7×10^{6}μm, divided by 100.1μm is 16980, which means that in the episode Morty's height is reduced by a factor of 16980.

The Roller Coaster

The amount of energy used to pull a roller coaster up a hill in a frictionless environment is given by:

$$E = mgh, \qquad (1)$$

where E is the gravitational potential energy, m is the mass of the roller coaster and its riders, g is the gravitational field strength of the Earth (roughly 9.81 ms^{-2}), and h is the height of the hill. The roller coaster will be based upon Storm Runner, a roller coaster at Hersheypark, Pennsylvania. Storm Runner consumes 2.5MW of power during operation, the ride's largest drop is 185 feet (56.4m), each cart weighs 10900kg and each ride lasts about 1 minute [4]. Each cart is capable of carrying 20 riders. With an average American adult over 20 years of age weighing approximately 80kg [5], each cart will have roughly 1600kg of rider if it is full. From here on, the mass of a full cart and its riders will be used as the cart's mass.

Substituting the values from Storm Runner into equation 1 gives a per ride energy requirement of:

$$E = mgh$$
$$E = (56.4m)\left(9.81N\,kg^{-1}\right)(12500kg)$$
$$E = 6{,}920{,}000J. \qquad (2)$$

If a ride takes one minute and the actual power consumption is 2.5MW, the actual energy consumption per ride is:

$$E = Power \times Time$$
$$E = (2{,}500{,}000W)(60s)$$
$$E = 150{,}000{,}000J. \qquad (3)$$

By dividing the theoretical value by the actual value, one would get an efficiency of 0.0461. Therefore, the roller coaster would require less than 5% of the energy it normally requires in order to operate in a frictionless vacuum. From here, the theoretical power usage of the miniaturized coaster can be calculated. It is worth noting that the scaling factor is in units of length, not mass. However, to scale down mass, the mass of the real cart can be divided by the scaling factor cubed (since it is being scaled in all three spatial dimensions). This is shown in equation 4 where mass is converted to volume via the density, scaled, and converted back to mass. Density does not need to be calculated to scale the mass since it cancels out by combining the above operations.

$$M_S = \frac{M_R D}{S_F^3 D}$$
$$M_S = \frac{12500kg}{16980^3}$$
$$M_S = 2.55 \times 19^{-9}kg, \qquad (4)$$

where M_S is the mass of the shrunken cart, M_R is the mass of the real cart, D is the density, and S_F is the scaling factor. The mass of the miniature cart is therefore 2.55×10^{-9} kg. As well, the drop height of the roller coaster needs to be calculated, which can be accomplished by dividing the real coaster's height by the scaling factor.

$$h_S = \frac{h_R}{S_f}$$
$$h_S = \frac{56.4m}{16980}$$
$$h_S = 3.32 \times 10^{-3}m, \qquad (5)$$

where h_S is the height of the miniaturized roller coaster, h_R is the height of the full-sized roller coaster, and S_F is the scaling factor. Therefore, the new height is 3.32×10^{-3} m. From here, equation 1 can be used on the miniaturized cart to calculate the energy requirement to pull it up the hill:

$$E = mgh$$
$$E = (2.55 \times 10^{-9}kg)\left(9.81N\,kg^{-1}\right)(3.32 \times 10^{-3}m)$$
$$E = 8.31 \times 10^{-11}J. \qquad (6)$$

Therefore, the potential energy is 8.31×10^{-11} J per ride. The energy requirement must be divided by the efficiency to get the real energy requirement:

$$Actual = \frac{Theoretical}{Efficiency}$$
$$Actual = \frac{8.31 \times 10^{-11}J}{0.0461}$$
$$Actual = 1.80 \times 10^{-9}J. \qquad (7)$$

The power consumption of the roller coaster can be calculated by dividing by the ride time:

$$Power = \frac{Energy}{Time}$$
$$Power = \frac{1.80 \times 10^{-9}J}{60s}$$
$$Power = 3.00 \times 10^{-11}W. \qquad (8)$$

This gives a power consumption of 3.00×10^{-11}W for the miniature roller coaster. Multiplying that by the number of seconds in a day gives the daily power consumption of one cart operating for 24 hours:

$$E = (3.00 \times 10^{-11}W) \times (60s)(60\text{min})(24h)$$
$$E = 2.59 \times 10^{-6}J. \qquad (9)$$

Therefore, 2.59×10^{-6}J are consumed per day. It will be assumed that the roller coaster runs for 12 hours per day and that it has three active carts, leading to a daily energy usage of 3.88×10^{-6}J or 9.27×10^{-10}kcal.

Conclusion

If the assumptions of this model are correct, then little power is required in order to run a roller coaster small enough to fit inside the human body. The roller coaster in question, modelled after Hershey Park's Storm Runner was calculated to require 9.27×10^{-10} kcal of energy per day, which is negligible compared to 2000 to 3000 calories an average American consumes per day.

References

[1] Health Canada (2004) *Estimated Energy Requirements*. Available at: http://www.hc-sc.gc.ca/fn-an/food-guide-aliment/basics-base/1_1_1-eng.php [Accessed 21 March 2017]

[2] Ochs, M., Nyengaard, J.R., Jung, A., Knudsen, L., Voigt, M., Wahlers, T., Richter, J. & Gundersen, H.J.G. (2004) *The Number of Alveoli in the Human Lung.* American Journal of Respiratory and Critical Care Medicine, vol. 169, pp. 120-124.

[3] Kuczmarski, R.J., Ogden, C.L., Guo, S.S., et al. (2002) *2000 CDC growth charts for the United States: Methods and development*. National Center for Health Statistics. Vital Health Stat. 11(246). Available at: https://www.cdc.gov/nchs/data/series/sr_11/sr11_246.pdf [Accessed 21 March 2017]

[4] Marsan, C. (2002) *Top tech roller coasters: These rip-roaring rides use the latest sensors, computers and networks to thrill and secure riders*, NetworkWorld from IDG. Available at: http://www.networkworld.com/article/2261029/infrastructure-management/top-tech-roller-coasters.html [Accessed 21 March 2017]

[5] Fryar, C.D., Gu, Q. & Ogden, C.L. (2012) *Anthropometric reference data for children and adults: United States, 2007–2010*. National Center for Health Statistics. Vital Health Stat. 11(252). Available at: https://www.cdc.gov/nchs/data/series/sr_11/sr11_252.pdf [Accessed 21 March 2017]