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A4_3 The Human Barbecue

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Abstract

This paper considers the feasibility of the Human Torch, calculating the energy taken to turn a human body to plasma, generate a large amount of heat for long periods of time, and how much food would need to be consumed to provide the necessary energy. Johnny Storm's secondary power of absorbing thermal energy from his surroundings is also calculated as another way of fuelling his flames. It is concluded that the energy required to maintain his plasma 'fire' state would be comparable to a coal-fired power station, equivalent to Johnny eating 41740 big macs per hour rendering his ability unfeasible.

Introduction

Johnny Storm is a member of the Fantastic Four, a group of superheroes with powers tied to the four elements as seen in Marvel Comics. Known as 'The Human Torch', Johnny has the fictional power of pyrokenesis which allows him to transform the molecules of his body into a high-temperature hydrogen plasma as well as manipulating the flow of heat in his surroundings and conjuring flames [1]. Each of these skills revolves around energy, with most of them expending large amounts.

Becoming a Plasma

In order to simplify calculations, the process of turning Johnny Storm into a plasma has been split into two parts: Firstly the energy required to break the bonds of his body and vaporise himself, and secondly the energy required to raise the temperature of his plasma body to his burning temperature of 10000 K [2]. Although Marvel Wikia states that Johnny burns at 416 °C (689K) [1], this is not physically high enough to create a hydrogen plasma in our universe and we use 10000 K, as stated above.

The first part of the calculation is the energy that needs to be put into the bonds of the body in order to break them into a plasma. This process vaporises the body, but does not imbibe any heat, meaning that the resulting plasma is at body temperature. The value of the energy needed to vaporise a human has been calculated by Stylianidis et al in a 2013 Physics Special Topics paper where a value of 2.99 GJ was reached [3]. The second part of the transformation requires the heating of the plasma, the energy for which can be found from;

$$Q = cm \bigtriangleup T. \quad (1)$$

Here, c=14.6 kJ kg^{-1} K^{-1} is the specific heat of hydrogen [5], m is Johnny's mass, and $\bigtriangleup$T is the difference between 10000 K and body temperature 310.5 K. This calculation assumes that Johnny weighs 77 kg. [1] Putting these values into eqn.(1) gives 10.9 GJ, which gives a total energy required to heat up Johnny and turn him into a plasma of 13.89 GJ.

An important assumption has been made here. In reality a hydrogen plasma has a much lower density than that of a solid human, however, the assumption is made that his entire mass has been converted from a solid state to a plasma state and that the plasma density is very large as to keep Johnny's volume similar to that in his solid state, as seen in the comics.

Maintaining a Flame

The amount of energy Johnny would need per second to maintain a flame can be found from,

$$\frac{Q}{t} = \frac{\kappa A(T_{hot} - T_{cold})}{d}. \quad (2)$$

The heat generated (Q) for time t=1 second relies on his surface area (A), environmental temperature (T_{cold}=15 °C (288 K), the heated temperature of the plasma (T_{hot} = 10000 K) and the thermal conductivity of hydrogen (κ=0.182 W m^{-1} K^{-1}) [4]. The average surface area of a human male is 1.9 m^2 as calculated by Sacco (2012) [6]. Finally d=0.05 m is the thickness of the barrier, here taken to be the average thickness from the centre of the plasma of his body. Thus the heat conducted away from him is 67.2 kW.

Energy is also radiated from him in the form of photons. If he is modelled as a black body the Stefan-Boltzmann law can be used,

$$j^{\star} = \sigma(T_{hot} - T_{cold})^4 = 50.4 \text{ MJ m}^{-2}\text{s}^{-1}. \quad (3)$$

$j^{\star}$ is the power per unit, T_{hot} and T_{cold} are as before and σ is the Stefan-Boltzmann constant which is 5.67×10^{-8} W m^{-2} K^{-4}. For the surface area of the Human Torch (1.9 m^2) the energy radiated per second is 95.76 MW.

The total energy Johnny would lose per second is equal to the conducted energy summed with the radiated energy which, as the radiated energy is much larger than the conducted energy, is approximately 96 MW.

Feeding the Fire

Once alight, the Human Torch requires a lot of energy to maintain his 'flame' for any significant amount of time. A McDonalds Big Mac contains 550 calories or 2300 kJ of energy [7] so he would have to eat 41740 Big Macs per hour to maintain his energy output. Sunflower oil has 34100 kJ per litre so he could alternatively drink 2816 L of oil per hour.

However his special ability of pyrokenesis gives him a second source of power. Johnny is able to draw thermal energy from his surroundings. As he is effectively transferring energy from a cold environment (the surrounding air) to a hot environment (himself) external work would be needed to transfer the heat. Modelling this scenario as a Carnot heat pump we get the following expression,

$$\eta = \frac{W}{Q} = \frac{T_{hot} - T_{cold}}{T_{hot}}. \quad (4)$$

W is work done, Q is the heat Johnny requires to keep himself in a plasma state, and the temperatures are as above [8]. This can be rearranged to find the work,

$$W = Q\left(1 - \frac{T_{cold}}{T_{hot}}\right). \quad (5)$$

In Johnnys case to replenish the 96 MW of energy lost per second 93 MW of work is required, which is 5-10 percent of the power output of a coal-fired power station [9].

Conclusion

Within the Marvel universe where pyrokenesis and human-plasma vaporisation exists, the Human Torch would still have to consume a huge amount of energy per second, comparable to a coal-fired power station and equivalent to eating 41740 big macs per hour. What has been calculated is his 'base flame', the minimum power for 'lighting himself up' and remaining in his plasma state. Within the comics, he is shown flying and shoot 'fireballs'. In these cases, he would need to consume even more energy which is unfeasible.

References

[1] `http://marvel.wikia.com/Jonathan_Storm_(Earth-616)`
[2] `http://www.wag.caltech.edu/home/jsu/Thesis/node31.html` Accessed on 27/10/2014.
[3] N. Stylianidis, O. Adefioye-Giwa and Z. Thornley, *Complete Vaporisation of a Human Body* (2013)
[4] `http://www.engineeringtoolbox.com/hydrogen-d_1419.html` Accessed 15/10/2014
[5] `http://www.engineeringtoolbox.com/hydrogen-d_976.html` Accessed 15/10/2014
[6] J. Sacco et. al, *The average surface area of cancer patients in the UK* (2010)
[7] `http://en.wikipedia.org/wiki/Big_Mac` Accessed 15/10/2014
[8] `http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/carnot.html#c2` Accessed 14/11/2014
[9] `http://en.wikipedia.org/wiki/Power_station#Typical_power_output` Accessed on 15/11/2014