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How much energy would be required for Game of Thrones dragon Viserion to destroy the Wall?

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Abstract
This paper calculates the amount of energy the *Game of Thrones* dragon Viserion had to produce and transfer to a section of the Wall in order to destroy it in the final episode of season 7. The energy was calculated to be 3.08×10^{12} kJ if he was flying 45 m away from the Wall and his 2 m long jaw opened at an angle of 45˚. The enthalpy of fusion and vaporising were used so to simulate the Wall melting from ice to water, being raised to boiling point and then vaporising. The amount of energy Viserion would have had to provide is extremely large and so errors in assumptions as well as the realism of the situation must be considered.

Introduction
The final episode of season 7 in the award-winning Game of Thrones (GoT) series ended dramatically with Viserion destroying the Wall and leading the army of the dead into Westeros [1].

Although away from the setting of GoT, dragons and White Walkers are far from real, it is still possible to investigate the iconic scene and how much energy Viserion would have had to produce to melt and vaporise the Wall.

To provide an answer for this query, assumptions must be made concerning the release of energy, and the dimensions of the Wall affected. Analysis of previous scenes in GoT were used to determine the approximate size of Viserion's head (2 metres long), opening jaw angle (45˚ by movement of his lower jaw) and the distance which he was flying from the Wall (45 m). It is also assumed the temperature of the ice was -10 ˚C initially.

Theory and application
Tackling this problem requires application of the First Law of Thermodynamics. As Viserion transfers energy to the ice wall the temperature increased proportionally. The amount of energy is dependent on the mass and heat capacity of the ice. The theory involves enthalpies; enthalpy of fusion H_f (the heat required for the ice to change states from solid to liquid) and enthalpy of vaporisation H_v (amount of energy needed to change the liquid water into gaseous form) [2].

The amount of energy needed to raise the temperature and melt the ice at 0 ˚C, raise the temperature of the now water to 100 ˚C and then vaporise the water is determined by the following equations relatively:

$$Q_f = m_1 H_f, \quad (1)$$
$$Q = m_2 c \Delta T, \quad (2)$$

and

$$Q_v = m_2 H_v. \quad (3)$$

Equations 1, 2 and 3 combined give the energy Viserion required to destroy the Wall.

However, Viserion does not destroy the whole 300-mile-long Wall but instead just the end at the edge of the sea [3]. Therefore, the exact masses used in the three equations must be calculated. In this paper, the energy calculated is the amount Viserion transfers to the ice directly straight in front of him in one moment.

It is assumed that the flame begins at the back of Viserion's mouth and spews out at an angle of 45 ˚C, illustrated below in figure 1.

It is estimated from analysing images of Viserion that the length of jaw is 2 m and the width of his mouth is half that of the jaw extension when at 45˚.

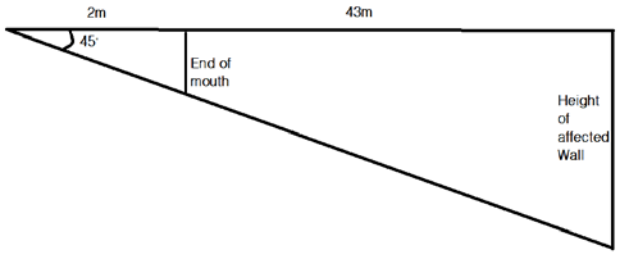

Figure 1 – A simplified diagram of the approximate measurements of the flame leaving Viserion and hitting the wall. It is drawn as if viewing from the right of Viserion, in the median plane.

From these assumptions and using trigonometry ($opposite = tan\theta \times adjacent$), the height of the Wall affected is 45 m. The length of the Wall affected was calculated using figure 2, in a similar manner to figure 1.

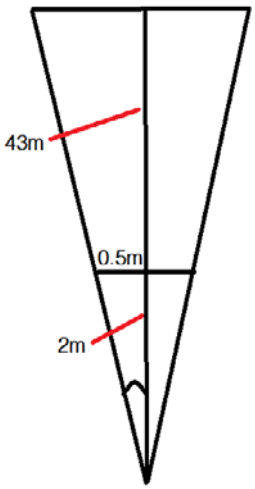

Figure 2 – The approximate dimensions of the flame acting horizontally on the Wall, viewed in the dorsal plane. Due to using trigonometry, the width of mouth and angle shown are half the true values.

The horizontal angle of the flame exit is therefore 28˚ having used trigonometry on the smaller triangle (the mouth) in figure 2. The length of the Wall targeted is 22.44 m. This was calculated using; half-length = $tan(14) \times 45\ m$ then multiplying this by 2 so to consider the whole length of Wall.

According to the GoT books, the Wall is wide enough to allow up to a dozen mounted men to ride along the top [3]. Hence, the width of the ice can be approximated to be 40 ft, or 12.19 m, assuming all horses are the same width.

The volume of the section of Wall can then be calculated to be (22.44 m × 45.00 m × 12.19 m) 1.23×10^4 m^3. With the density of ice being 0.9167 g cm^{-3}, the mass of ice (m_1) is 1.1×10^9 g. When it is melted the mass of the water (m_2) will be the same as the ice, however the volume would have changed. It is assumed sublimation does not occur.

The energy from the flame melting the section of the Wall is equal to sum of energies from equations 1, 2 and 3 (with m_1 equalling the ice mass and m_2 the water mass). As the Wall has an initial temperature of -10 ˚C, there is an energy requirement to increase the temperature to 0 ˚C. The calculation and values for the total energy requirement are show below [4]:

$$Energy = m(c\Delta T_1 + H_f + c\Delta T_2 + H_v)$$

$$\begin{aligned} Energy\ = \ & 1.1 \times 10^9 g\ [\ (2.1\ Jg^{-1} \times\ 10\ K) \\ & +\ (334\ Jg^{-1}) \\ & +\ (2.1\ Jg^{-1} \times\ 100\ K) \\ & +\ (2030\ Jg^{-1})] = 3.08 \times 10^{12}\ kJ \end{aligned}$$

This paper assumes this occurs within a closed system and so there is no energy lost. Therefore, hypothetically the energy calculated would be the minimum amount required.

Conclusion

From using the estimated values of the dimensions of Viserion, the distance he was from the wall and the determined measurements of the target mass, the energy required to destroy part of the Wall is 3.08×10^{12} kJ. This is a large amount of energy for a relatively small section of the Wall and theoretically is less than what Viserion would have provided as he continued along the Wall without pausing, destroying it. He is also flying at the time whilst carrying the weight of the Night King and so energy is also being used for this. There is room for error in the calculations due to the fact there are few exact measurements provided from the books or television series and so estimates had to be made.

References

[1] Martin, G.R.R., Benioff, D. & Weiss, D.B. (2017) *The Dragon and the Wolf*, Season 7 Episode 7. HBO. First Broadcast 28 August 2017.

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[3] Martin, G.R.R. (2011) *A Dance With Dragons*, New York: Bantam Books

[4] Engineeringtoolbox.com (2018) *Water - Thermophysical Properties*. Available at: https://www.engineeringtoolbox.com/water-thermal-properties-d_162.html [Accessed 16th March 2018]