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P1_1 Cooking on Titan

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Abstract
Titan, Saturn's largest moon, is the celestial body with an atmosphere most similar to that of Earth's, in our solar system. Little is known about Titan's surface. However, its atmosphere is a crucial element that makes Titan a potential candidate for human exploration. If Titan were habitable, a sustainable source of food would be required. This paper considers the energy that would be required to do so as compared to that on Earth. We found that cooking a portion of rice uses 610kJ on Earth and 1054kJ on Titan, so 1.7 times more energy is required on Titan.

Introduction

Titan is the only moon in the solar system known to have an atmospheric pressure similar to that of Earth. Its atmosphere greatly obscures our line of sight when we attempt to observe it, so little is known about Titan's surface. As a result, it is of great scientific interest. Therefore it is important to consider whether survival would be possible and hence, consider a method of providing sustenance for potential explorers. Whilst cooking, rice undergoes a process called gelatinization. This process occurs when the starch granules absorb water and lose their crystallinity, which requires heat and moisture [1].

Thermodynamics of cooking rice

On Earth: To cook the rice, we must boil it in water. Therefore we must consider the energy required to heat the water and rice. This can be done using the following equation,

$$Q_{\Delta T} = mC\Delta T, \tag{1}$$

where $Q_{\Delta T}$ is the energy required to heat the water, m is the mass, C is the specific heat capacity and ΔT is the change in temperature. We assumed the starting temperature was room temperature 293K). During the cooking process, some of the water used to cook the rice will evaporate, requiring additional energy. This energy is given by,

$$Q_{vap} = ml_{vap}, \tag{2}$$

where Q_{vap} is the energy required to vaporise the water and l_{vap} is the latent heat of vaporisation. On Titan, the cooking process is the same as on Earth, so we must consider the same variables. However, maximum and minimum temperatures of the water will be different from that on Earth. Firstly, the ambient pressure on Titan is different to that on Earth which affects the vaporisation temperature. This is shown in Figure 1. We can calculate the vaporisation temperature on Titan using the Clausius Clapeyron equation [2],

$$T_2 = \frac{1}{(\frac{1}{T_1} + \frac{R}{l_{vap}} ln(\frac{P_1}{P_2}))}, \tag{3}$$

where T_1 and T_2 are the boiling temperatures at pressures P_1 and P_2 respectively, R is the molar gas constant. Furthermore, the ambient temperature on Titan is much lower than that on Earth

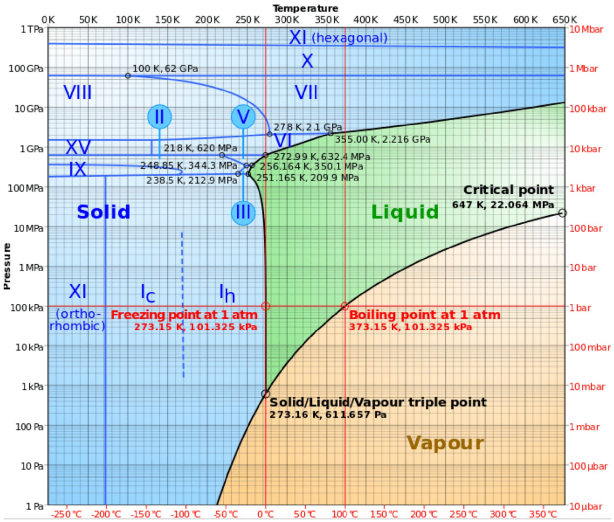

Figure 1: A phase diagram of water. [3]

(94K [4]), so any stored water would be frozen. This means that we must also consider the energy required to melt the ice whilst heating it. This energy is given by

$$Q_{fus} = ml_{fus}, \tag{4}$$

where Q_{fus} is the energy required to melt the ice and l_{fus} is the latent heat of fusion.

Calculations and discussion

To do these calculations we used a conventional recipe for white rice, using 1/2 a cup of rice and 1 cup of water. Using the density of water and bulk rice [5], and the volume of a cup, we calculated that this recipe uses 475g of water and 140g of rice. We assumed that during the cooking process, the rice triples in weight by absorbing water [6]. Therefore, after cooking we are left with 420g of cooked rice, meaning that 191g of water must evaporate. The total energy used in the cooking process is simply the sum of the energies required. On Earth, $Q_{tot} = Q_{\Delta T_{water}} + Q_{\Delta T_{rice}} + Q_{vap} = 610\text{kJ}$ where $\Delta T = 80\text{K}$. On Titan, the atmospheric pressure is about 1.45atm [4]. Using equation (3) we calculated that the boiling point of water on Titan is 111K, giving us $\Delta T = 290\text{K}$. Again the total energy used in the cooking process is the sum of the energies required. Therefore on Titan, $Q_{tot} = Q_{\Delta T_{ice}} + Q_{\Delta T_{water}} + Q_{\Delta T_{rice}} + Q_{fus} + Q_{vap} = 1050\text{kJ}$. From these results we can see that it takes roughly 1.7 times the energy to cook rice on Titan compared to Earth. This additional energy requirement would certainly be problematic as energy is typically at a premium in space exploration. In both cases, 432kJ is required to vaporise some of the water, which corresponds to 71% and 41% of the total energy required on Earth and Titan respectively. Using a sealed container (i.e. a pressure cooker) would drastically reduce the water that would vaporise, reducing the energy needed. Furthermore, it may be possible to cook the rice at a lower temperature with less water, again reducing the energy lost through vaporisation and the energy required to heat the water.

Conclusion

The results show that the energy needed to cook a portion of rice on Titan is 1045kJ, roughly 1.7 times that on Earth (610kJ). A large proportion of the energy required comes from vaporising some of the water. By altering the cooking method, the amount of water vaporised could easily be reduced, reducing the energy required.

References

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