Journal of Physics Special Topics

P6_7 The Perfect Cuppa: The Search for the Best Place in the Solar System to Brew a Cup of Tea

A. Pohl, J. McGuire and A. Toohie

Department of Physics and Astronomy, University of Leicester. Leicester, LE1 7RH.

Nov 7, 2013.

Abstract

In this paper we calculate the boiling point of water in several locations around the solar system and describe the effects on the human body of drinking water at this temperature. We are able to conclude that Titan is the only body in the solar system with an atmosphere thick enough to allow the production of a cup of tea like those made on Earth on its surface (albeit a fairly cold one), while the Martian surface would facilitate production of a beverage resembling a refrigerated drink or ice-cream. Venus could prove useful for making a cup of tea if a floating platform could be constructed on the planet.

Introduction

This paper will discuss the possible locations in the solar system where the pressure is in the right range to make a cup of tea. The optimum temperature for drinking a cup of tea is $60°C$ [1]. We will assume that it is possible to create any temperature difference between the planets atmosphere and the water. It will then discuss any ill effects of consuming the fluids at the temperatures calculated. This paper will not discuss the practicalities of boiling water in these locations or the reactions between the water and the atmosphere of the planet, nor will we consider the feasibility of humans surviving the conditions.

Theory

To find the temperature at which water boils at a given pressure we use the Clausius-Clapeyron equation [2]:

$$\ln(P_2/P_1) = (\Delta H_V/R)\left[(1/T_1) - (1/T_2)\right] \tag{1}$$

where T_1 is the boiling point at a pressure P_1 and T_2 is the boiling point at pressure P_2, ΔH_V is the enthalpy of vaporisation of water, $44kJmol^{-1}$ [3], R is the molar gas constant, $8.314Jmol^{-1}K^{-1}$ [4]. We call the pressure on the earth at sea level P_1, which can be taken to be $101.3kPa$ at a temperature of $373K$ [5], and call the pressure on the planetary surface we examine P_2. Eq. 1 can be rearranged to give

$$T_2 = \left[1/T_1 - (R/\Delta H_V)\ln(P_2/P_1)\right]^{-1}. \tag{2}$$

The Moon

The obvious first stop on a tea-drinking tour of the Solar System is our nearest celestial neighbour, the Moon. The average pressure on the moon is $0.3nPa$ [6], giving a boiling point of $111K$ ($-162°C$). Attempting to drink a fluid approximately 50K warmer than liquid nitrogen [7] would cause severe gastrointestinal problems. Using the specific heat formula $E = mc\Delta T$, where E is the change in energy of a material, m is the mass of the material, c is the specific heat capacity of the material and ΔT is the change in temperature, it is possible to quantify the implications of drinking such an icy brew. We assume now that the temperature of the tea and the body equilibrate upon drinking and the body is initially at $37°C$. Taking a specific heat capacity of flesh of $3.75Jg^{-1}K^{-1}$ [8] and a specific heat capacity and density of water of $4.19Jg^{-1}K^{-1}$ [9] and $1000kgm^{-3}$ [10] respectively, assuming the density of water is almost invariant with temperature, a $50kg$ human drinking a $500ml$ cup of tea would give an equilibrium temperature of $34.8°C$, a drop of $2.2K$. This is more than enough to cause severe and irreversible damage to internal organs.

Mars

It has been suggested repeatedly that Mars is one of the more likely planets for terraforming [11] [12]. It has a surface pressure of $0.7kPa$ [13], producing a boiling point of water of $276K$ ($4°C$) from Eq. (2), slightly warmer than the ideal serving temperature for ice-cream [14]. By inspection, although this is far from an ideal temperature for tea, it is a temperature at which tea would be safe to drink. If we repeat the previous calculation, we see that the resulting cooling effect on $50kg$ of flesh is just $0.37K$.

Marianas Trench

In our search for the perfect brew we need not necessarily look to the heavens. The Marianas trench is the deepest point on the surface of Earth, with a depth of 11km. It has only ever been explored by two people [15]. The average pressure at the bottom of the trench is $1.235MPa$ [15], yielding a boiling point of $453K$ ($180°C$). At this temperature, the tea is likely to cause significant scalds both to the mouth and digestive tract. As before, the consequences for the average $50kg$ human would correspond to a temperature rise of $1.58K$.

Titan

Titan is the second largest moon in our Solar System, in orbit around Saturn [16]. The average pressure on Titan is $1.6kPa$ [17], which corresponds to a boiling point of water of $289K$ ($16°C$). At this temperature the tea would be unpleasant, but drinkable, and corresponds to a temperature drop in the human body of $0.24K$.

Venus

Venus is home to some of the harshest conditions in the Solar System [18]. The incredible temperatures and pressures make human exploration of the planet very difficult. It is for this reason that a nice cup of tea would be very well received by anybody who does venture onto the surface. The pressure on the surface is $9MPa$ [19]. At this pressure the tea would have to heated to $546K$ ($273°C$). This would cause an increase in body temperature of $2.6K$.

Conclusion

Although it would be possible to make a cup of tea on the Moon, drinking it afterwards would be ill advised (although a steaming cup of tea could provide a soothing visual reminder of Earth for any prospective Lunar settlers). A cup of tea on Mars would be safely consumable, however it would not be of a reasonable temperature. If one desired a cup of iced tea, the situations on Mars would be somewhat ideal. It would be possible to drink a cup of tea in the Marianas Trench (if you could boil it) if there was time to let it cool slightly. On Titan we could drink the tea without damage, but it would probably be unpleasant to do so. Obviously tea on Venus is not suitable for drinking at all. There does exist on Venus a layer of the atmosphere at a pressure of exactly $1atm$. This occurs at roughly $50km$ from the planet's surface [18]. At this point tea would obviously boil at $100°C$ just as it would on Earth, and would be suitable for drinking. It may be logical then to build a floating platform on Venus before attempting any surface exploration, to ensure explorers still have access to tea on the planet.

References

[1] http://www.northumbria.ac.uk/sd/academic/lifesciences/news/2025163/ accessed on 16/10/2013.
[2] http://www.science.uwaterloo.ca/ cchieh/cact/c123/clausius.html accessed 30/10/2013.
[3] http://www.engineeringtoolbox.com/saturated-steam-properties-d_457.html accessed 12/11/2013.
[4] Tipler and Mosca (2008), *"Physics with Modern Physics for Scientists and Engineers"*. 6^{th} edition (570), W. H. Freeman and Company.
[5] http://www.engineeringtoolbox.com/pressure-d_587.html accessed 30/10/2013.
[6] http://nssdc.gsfc.nasa.gov/planetary/factsheet/moonfact.html accessed 30/10/2013.
[7] http://education.jlab.org/qa/liquidnitrogen_01.html accessed 30/10/2013.
[8] K. Giering et al., Thermochimica Acta. **251**, 199-205 (1995).
[9] http://hyperphysics.phy-astr.gsu.edu/hbase/thermo/spht.html accessed 30/10/2013.
[10] http://www.thermexcel.com/english/tables/eau_atm.htm accessed on 10/10/2013.
[11] R. L. S. Taylor, Adv Space Res. **22**, 421-432 (1998).
[12] D. Whitehouse (Feb 4, 1993). "Warm Glow for the Red Planet". *The Guardian*, pp. 12-13.
[13] http://science.howstuffworks.com/mars5.htm accessed 30/10/13.
[14] http://www.idfa.org/news–views/media-kits/ice-cream/storing-and-handling-tips/ accessed 30/10/13.
[15] http://deepseachallenge.com/the-expedition/mariana-trench/ accessed 30/10/2013.
[16] R. A. Jacobson et al., Astron J. **132** 2520-2526 (2006).
[17] P. Rannou et al., Adv Space Res. **36**, 2194-2198 (2005).
[18] L. V. Zasova et al., Planet Space Sci. **55** 1712-1728 (2007).
[19] P. Martin and E. Stoffan, Phys Educ. **39** 267 (2004).