Pressure on the boiling point

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The record pressure from the January 2020 anticyclone was readily noticed on barometers (Burt, 2020), but perhaps its most fundamental physical effect – changing the boiling point of water – might not have been so obvious. One definition of boiling point is as the temperature at which the vapour pressure from the liquid equals the pressure surrounding the liquid. Increase the atmospheric pressure, and the boiling point will therefore increase. Decrease it, such as by climbing a mountain, and the boiling point will drop. This physical response provided the basis for the pressure hypsometer, a classical explorer's instrument used to determine altitude by measuring the boiling point of water.

Could the 2020 anticyclone have produced a measurable change in the boiling point? This can be calculated. Many formulae are available for the vapour pressure and temperature in the usual meteorological range (e.g. Harrison, 2015), but the venerable equations of Goff and Gratch (1946) extend to 100 °C. Figure 1a shows the calculated vapour pressure using these equations, with the region around 100 °C of particular interest. At 100 °C, the gradient is 36.2 hPa $°C^{-1}$, or about 0.028 °C hPa^{-1}. Hence, at a sea level pressure of 1050 hPa, the increase in boiling point from that at the standard atmosphere of 1013.25 hPa would be about 1 °C, which ought to be readily measurable. Other questions arise such as the purity of the water and how the boiling point should be determined, as there are specific instruments – ebulliometers – solely intended to do this.

Given the immediacy of an interesting measurement opportunity, with the anticyclone about to drift away, the available apparatus to investigate this became nothing more than a kettle and a platinum resistance thermometer, with the thermometer pushed down the spout into the liquid. Reading tap water was used, passed through a deioniser resin. The kettle was boiled repeatedly, and the maximum temperature recorded each time. Further measurements were made on different days with apparatus unchanged, as the atmospheric pressure fluctuated. Figure 1b shows the median boiling point obtained on the different days, plotted against the station pressure: a change with pressure is clearly observed. In fact, the sensitivity found using a least squares fit is (0.0288 ± 0.007)°C hPa^{-1}, close to that calculated. The absolute difference is not so readily explained. It may be related to the boiling region sampled - long recognised as difficult to identify (Chang, 2007)- or a feature of the kettle itself, which had not been scrupulously cleaned.

What might be the effect of the elevated boiling point? One obvious consideration is the energy required to heat kettles during anticyclones. This is unlikely to ever be observable because of associated weather changes which would dominate. An estimate of the possible effect on energy consumption is however provided by the "TV Pickup" national power surge which occurs as kettles are boiled at half time in football matches or breaks in soap operas. An extra 2000 MW is typically required in the UK (BBC, 2007). Heating a similar number of kettles from 20 °C to 101 °C rather than 100 °C would require about 1% more energy, so therefore 20 MW of extra power might be needed nationally. This is comparable with the output of a small biomass power station, or about 20 times less than the reduction in wind power generation during the 2015 eclipse (Harrison and Hanna, 2016). Beyond raw energy consumption, a much more socially important effect might arise if there was any detectable taste change in a temperature-critical beverage for which the water was boiled, such as tea.

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Figure 1

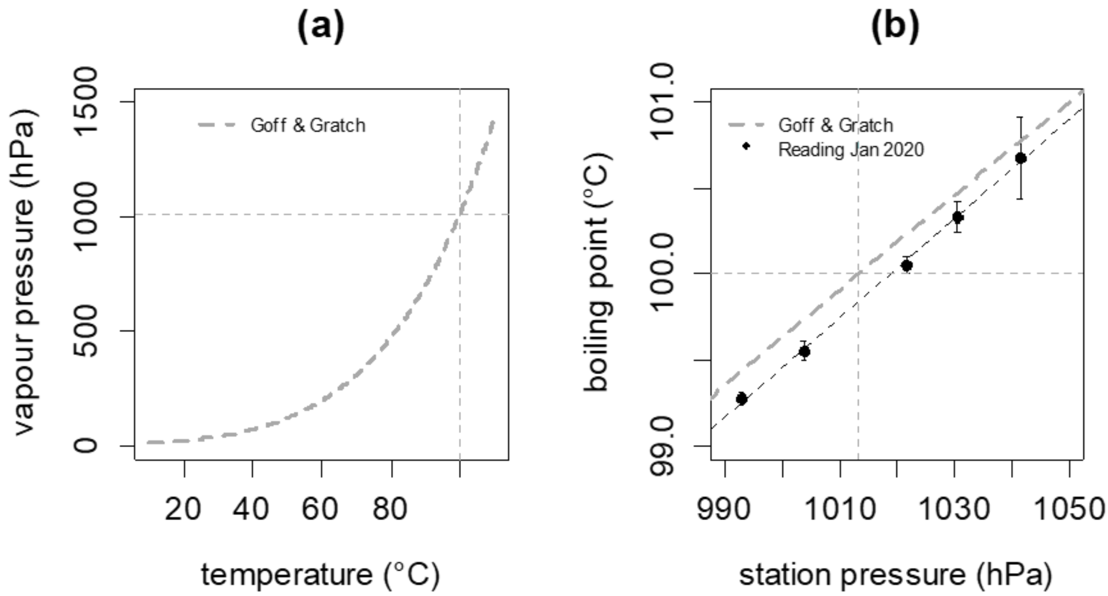

Figure 1 (a) Saturation vapour pressure over water, as calculated from the fit of Goff and Gratch (1946), with 1013.25 hPa and 100 °C marked. (b) Boiling point of deionised Reading tap water measured during January 2020, using a Digitron T600 precision platinum resistance thermometer and a Druck DPI 141 vibrating drum barometer (uncertainty ±0.15 hPa). A portion of the vapour pressure curve (grey dashed line) from (a) is shown in (b), with a least-squares fit to the data (dashed black line). Repeated boiling point determinations were made on days having different pressure values, with the median value shown for each case. Uncertainty bars represent the sampling error and the instrument accuracy, after correction for instrument bias at the ice point.