

**LABORATORY SIMULATION OF THE RELEASE OF SUBSURFACE WATER AND BRINE ON TO THE SURFACE OF MARS AND ICY SATELLITES.** A. S. Bargery, S. J. Lane, L. Wilson, J. S. Gilbert, Department of Environmental Science, Lancaster University, Lancaster LA1 4YQ, UK (a.bargery@lancs.ac.uk or alis-tair.bargery@univ-nantes.fr).

**Introduction:** For most extraterrestrial studies of volcanic and aqueous activity, the processes involved can be studied only by theoretical modelling, simulation in analogue experiments, or examination of the geomorphological and geological record. The last of these approaches is limited by the spatial resolution and coverage of satellite data, or to the very limited localities where rovers or landers have been deployed (e.g., Viking, Mars Exploration Rovers). There have been no observed releases of water on to the surface of Mars. Therefore, a series of experiments should add insight to our understanding of this phenomenon. The experiments are intended to be primarily a study of the temperature-pressure relationships and how they affect phase changes in both pure water and NaCl brines released on to the surface of Mars.

**Apparatus and methodology:** The apparatus used in the experiments consists of a Pyrex tube, with an internal diameter of 25.7 mm (therefore a surface area of 518.7 mm<sup>2</sup> is exposed to the atmosphere), housed within a cylindrical, 0.025 m<sup>3</sup> pressure chamber made of toughened glass. A magnetic mixer was used to create a brine of the required salinity. The pressure chamber was evacuated using a rotary oil pump. The height of the tube is such that it fits inside the pressure chamber, whilst enabling a sufficient depth of water to be tested in the experiments. It also allows enough height above the surface of the water for the spray from boiling and gas exsolution to be contained within the tube, so keeping the inner surface of the pressure chamber as dry as possible. There is no need for a CO<sub>2</sub> atmosphere to simulate water behaviour on Mars, because on Mars, both the H<sub>2</sub>O and the CO<sub>2</sub> in the local atmosphere above the water would have similar partial pressures since the atmosphere would be saturated with H<sub>2</sub>O. In fact, by allowing the atmosphere in the pressure chamber to become almost entirely water vapour, the experiments simulate the local atmosphere that would occur above an evaporating water body on Mars. There are therefore no buoyancy effects on the water evaporation rate, as water is evaporating into water vapour. Hence no correction to evaporation rate data is necessary with these experiments, as was required with previous experiments [1].

**Results:** Observations are presented that were made during each experiment, including both quantitative and qualitative data. Quantitative data include chamber pressure as a function of time, and water and

brine temperature as functions of time and depth. Ice thickness growth rate is measured and results are compared with a model. It is shown that the pump rate is similar for each of the experiments. The experiments operate at P-T conditions very close to the triple point of water, and so the phase changes involved are complex.

During the initial stages of the pure water experiments, boiling occurred in the top few centimetres, leading to forced convection and disruption of the boundary layer and loss of heat as water escaped from the liquid. After this initial stage, boiling became intermittent so forced convection almost ceased, but evaporation continued after boiling had ceased. It is interesting to note that there is more variability in the pressure at the final boiling event between the pure water experiments than between the salt solution experiments. This suggests that there may be some super-cooling effect in the pure water.

The pressure curves can be related to observations made concerning the phase changes. The pressure data as a function of temperature data show that the temperature decreases with pressure in a complex manner. For temperatures near to the freezing point, the pressure varies considerably. The results show how the surface temperature varies over the course of the experiment, with an initially high rate of cooling, a shallow gradient near the freezing point, and an increased rate of cooling once the water begins to freeze. They show the way in which the temperature varies with depth, and the temperature gradient at selected times, therefore giving insight to the thermodynamical processes operating within the ice-water system.

**Data analysis:** Evaporation rate is here expressed in terms of volume loss rate (measured from the water depth variation with time, to the nearest mm). These measurements can be converted to mass loss rates using the fact that mass is equal to the product of volume and density. However, the density of the water varies with temperature, so it is more convenient to work with volume loss rates. The average volume loss rate over a one-hour period was observed to be 0.0519 ml s<sup>-1</sup> for pure water initially at 289 K, reducing to 0.0021 ml s<sup>-1</sup> for saturated brine at the same temperature.

The average evaporation rate as a function of salinity was recorded. The evaporation rate is inversely proportional to the salinity of the water. It is difficult to calculate precisely the experimental uncertainty on a particular result but, from the scatter of data about the

quadratic trend line for evaporation rate against salinity, the  $R^2$  fit to the data is 97.45 % for evaporation rate. The error in the temperature was  $\sim \pm 1$  K.

We also consider the variation of evaporation rate ( $dv/dt$ ) with salinity ( $c$ ), and the variation of evaporation rate with water temperature ( $\theta_i$ ). Following our data analysis, an empirical relationship between  $dv/dt$  and  $c$  may be stated as  $dv/dt = 7 \times 10^{-6} c^2 - 0.0015 c + 0.0886$ , where  $c$  is expressed as a % saturation. The equation is valid for  $0\% < c < 100\%$ . Similarly, an empirical relationship between  $dv/dt$  and  $\theta_i$  may be stated as  $dv/dt = -6 \times 10^{-4} \theta_i^2 + 0.4426 \theta_i - 0.9986$ . It is noted that the experimental results (and therefore these empirical relationships) are probably sensitive to the ambient temperature; further investigation of the dependency of evaporation rate on the ambient temperature would help to resolve this issue.

**Discussion:** The experimental results show that at atmospheric pressures ( $P_a$ )  $> \sim 600$  Pa, freezing of pure water does not occur unless additional cooling mechanisms (e.g., the wind, radiative, convective and conductive cooling) are operating. Freezing through evaporation was predicted to occur on Mars [2, 3], but this seems to be contrary to our findings. Ice will not form just as a consequence of evaporation at  $P_a > \sim 600$  Pa. However, the effects of changes in the ambient temperature were not investigated and freezing of pure water at atmospheric pressures of approximately 600 Pa may be sensitive to such changes.

If ice has formed from freezing liquid water on Mars in the past, then it would most likely have been in the regions of lower atmospheric pressure ( $< 600$  Pa) or else where cooling processes other than evaporation due to the vapour pressure are also operating. In view of the observational results of the experiments, ice that forms on the surface of pure water would be neither compact nor entirely clear, nor would it have a smooth surface. Soon after the ice started to form, the ice would become porous at the millimetre scale due to rapid sublimation under low pressure. Water molecules would have escaped from the surface of the ice heterogeneously because of variations in ice crystal orientation, fractures, lattice boundaries, or defects within the ice. This would have created a surface that had a greater area than would otherwise be present with a smooth surface. A greater surface area increases the total heat flux from the surface.

The surface of the ice turned from clear to white during the experiments, implying that the ice reflected more of the incident radiation, as a consequence of a higher albedo. The higher reflectivity means that the ice will absorb less radiation, hence reducing the energy flux into the ice. Both of these factors acted to cool the ice more than for clear ice, through which most of the incident radiation penetrated to the water

beneath. Another subtlety that arose as a consequence of an irregular surface was that, although the sublimation rate may have increased, the number of molecules escaping may not. This is because the shape of the surface may have been such that it trapped many of the molecules attempting to escape.

Where atmospheric pressures are  $< \sim 200$  Pa, any pristine ice that forms from pure water will exhibit a ‘honeycomb’ surface that will be white and snowy. This includes certain high-altitude areas on Mars and the entire surfaces of the icy satellites of the outer solar system. The experimental results show that at an atmospheric pressure of  $< \sim 600$  Pa, both boiling and freezing of pure water occurs. This confirms the theoretical predictions of previous workers for Ganymede [4].

**Conclusions:** To cool a body of water such that a layer of ice may develop purely from heat loss by evaporation would be unlikely at present Martian atmospheric pressures, because 600 Pa is the saturated vapour pressure of water at the triple point. This result would be sensitive to changes in local pressure and temperature. This result is for a laminar situation; freezing by evaporation only would be even less likely with turbulent flow (because all of the water would have to cool to the freezing point). However, at pressures below approximately 600 Pa, boiling acts to cool the water rapidly, leading to freezing. Salt has a large effect on the vapour pressure and even concentrations as low as 10 % (further investigation would show if this is the case with concentrations  $< 10\%$ ) would prevent water freezing on Mars (the sensitivity to local pressure and temperature variations would be removed). At lower pressures, a mushy layer would form. Either way, this would provide a means for water to travel long distances without entirely freezing or evaporating, confirming theoretical suggestions (first proposed by [5]). Ice may form from other, non-evaporative cooling mechanisms, such as conduction, convection and radiation.

The experiments have shed new light on the nature of ice forming under low pressures. On Mars, where the water likely contains substantial concentrations of salt, any ice that does form will be in a mushy layer such as is the nature of terrestrial sea ice. This two-phase, porous medium is formed by pressure reduction as well as by temperature reduction. If the water does not contain any salts, then in low-pressure regions, the ice will exhibit a honeycomb structure.

**References:** [1] Sears D. W. G. and Chittenden J. (2005) *GRL*, 32, L23203. [2] Heldmann J. L. et al. (2005) *JGR*, 110, E05004. [3] Leask H. J. et al. (2006) *JGR*, 111, E8. [4] Allison M. L. and Clifford S. M. (1987) *JGR*, 92, (B8), 7865-7876. [5] Komar P. D. (1979) *Icarus*, 37, 156-181.