RHEOLOGY OF WATER-AMMONIA ICE: FIRST RESULTS; W. B. Durham, UCLLNL, Livermore, CA 94550; S. H. Kirby and L. A. Stern, USGS, Menlo Park, CA 94025

Temperatures were probably low enough in the solar nebula to condense ammonia-water mixtures at the orbit of Saturn and beyond (1). The proportion of ammonia estimated to have existed in the solar nebula, about 15% of the concentration of water (1), would have been sufficient to condense large volumes of solids with melting temperatures well below that for water ice. Thus, internal activity and surface tectonics, evidenced from the Voyager images (2), would be plausible at the low temperatures of the outer solar system.

The rheology of solid mixtures of water and ammonia ice is currently unknown. As a result, models of tectonic processes on ammonia-rich bodies suffer from lack of constraint. To remedy this problem, we have recently undertaken an experimental study to determine the rheological properties of ammonia-water solid mixtures under the pressure and temperature conditions that exist within the icy moons. We report here the initial results of that study.

Our methods are analogous to those we used earlier to determine the rheology of pure water ice (e.g., 3), adapted to much lower temperatures. Cylindrical samples are synthesized in the laboratory by freezing mixtures of sieved seed water ice and ammonia-water liquid in a specially constructed manifold (Figure 1). The seed ice is intended to keep grain sizes small and to suppress the formation of a preferred crystallographic orientation of the grains. The samples have a diameter of 25.4 mm and a length of approximately 60 mm. To date we have made samples only with bulk composition 15 wt% NH_3. The equilibrium composition of the resultant solid is 45 wt% $NH_3 \cdot 2H_2O$ (ammonia dihydrate) and 55 wt% water ice. At this point we cannot rule out the possibility that monohydrate ($NH_3 \cdot H_2O$) and/or glass exist metastably in the samples. Prior to mechanical testing, the samples are jacketed in indium tubes and capped at either end with stainless steel discs, forming a pressure-tight encapsulation. All handling of the solid material is done at temperatures below 173 K. Above that temperature a eutectic liquid, with a composition near that of dihydrate, will form. Incidentally, such a liquid has been suggested by many as a possible source of surface volcanism on some of the icy moons.

We have performed preliminary constant deformation rate experiments at a fixed confining pressure of 50 MPa over temperatures from 137 to 162 K and strain rates from 4×10^{-6} to 4×10^{-4} s^{-1}. At 137 K we could not deform the material in a ductile manner despite imposed differential stresses up to 800 MPa. At the higher temperatures, plastic deformation did occur. The flow appears to be nonlinear, with a stress exponent about 6 and an activation enthalpy of 65 kJ/mole. At T = 152 K and a strain rate of 4×10^{-5} s^{-1}, the flow stress is approximately 65 MPa.

Flow in two phase materials is bound to be complex, and the above characterization of the rheology in terms of a stress exponent and activation enthalpy is probably an oversimplification. We already know, for example, that a few degrees above the eutectic, our material has practically no strength. For the moment, the results are consistent with the idea that a moon with ammonia is considerably weaker than a pure water moon. Upcoming work will test the effect of varying the concentration of NH_3 in the sample and the effect of partially melting the samples.

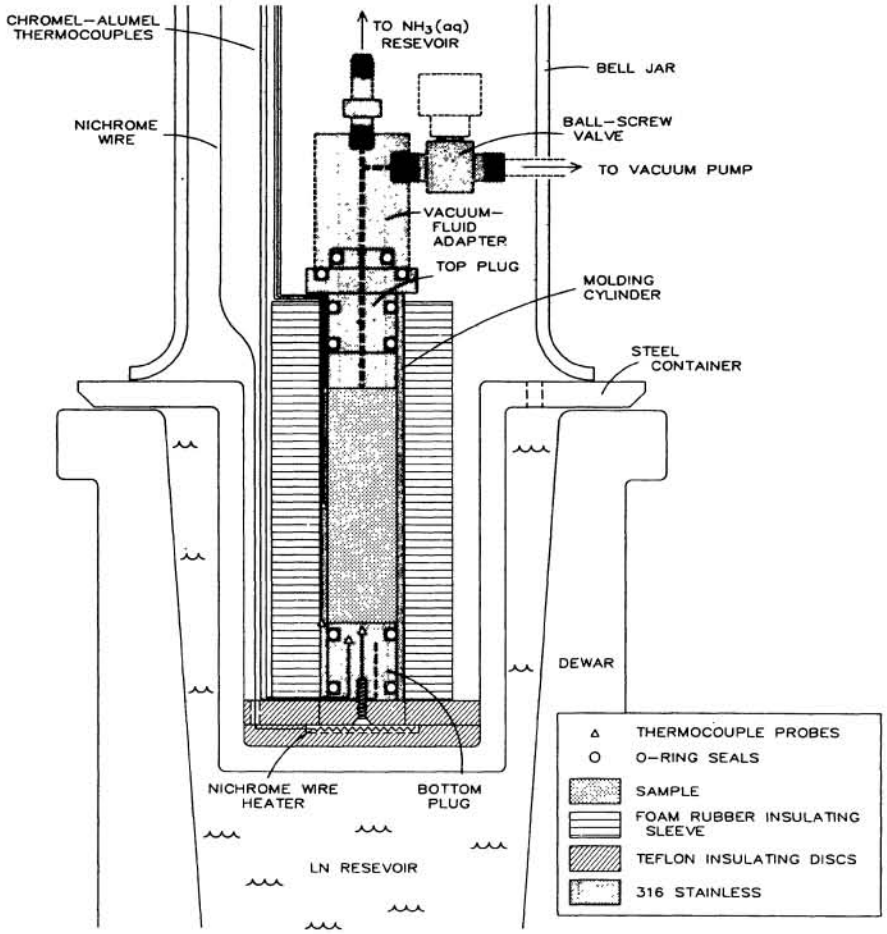

Figure 1. Molding apparatus for making samples of ammonia-water ice. Seed material made of pure H_2O ice sieved to a uniform size of about 1 mm is introduced into the molding cylinder. The cylinder is then evacuated and aqueous NH_3 is fed into the chamber. Freezing proceeds from the bottom upwards to exclude gas bubbles. Temperatures are monitored with several thermocouples and controlled with a small resistance heater below the bottom of the chamber.

References

(1) Lewis, J. S. (1972) *Icarus, 16*, 241-252.
(2) Morrison, D. et al. (1984) in *Saturn*, pp. 609-639. University of Arizona Press, Tucson.
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