Thermal quenching phenomena in liquid nitrogen

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Quenching of a material in a liquid nitrogen pool exhibits a rich mix of hydrodynamical and thermal phenomena. Initially material at room temperature is surrounded by a vapor film, which insulates the material, limiting the heat transfer rate. As the temperature difference between the material and the pool reduces, the film collapses initiating direct contact of the fluid to the material, increasing the heat transfer. This transition is dependent on the material thermal conductivity, surface roughness, and the pool thermodynamic state.

With the help of optical imaging and thermometry, we studied the quenching characteristics of a cylindrical vial and found that with a coating of poor conducting material the vapor film collapses at a higher vial temperature compared to the bare surface. This trend is also observed while sub-cooling the pool. In addition, the critical heat flux increases with increasing sub-cooling temperature.

Sub-cooling of a pool of liquid nitrogen bath can be achieved by injection of non-condensable gas. It is assumed in the literature that the cooling efficiency of a single bubble is independent of the bath conditions. However, we show using high speed optical imaging that the efficiency is a strong function of the bath temperature and increases exponentially towards the saturation temperature.

Our study gives new insights into the thermal processes during quenching of materials, leading to potential improvement of applications in which rapid cooling is essential, such as cryopreservation of tissue and superconducting power equipment.