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A Temperature Instability in 4 K Cryocooler Regenerators Caused by Real Fluid Properties

R. Snodgrass, V. Kotsubo, J. Ullom, and S. Backhaus, NIST, Boulder, CO

The thermodynamic and fluid properties of helium vary dramatically at pressures near 1 MPa and temperatures below 30 K. Depending on the temperature, these properties can either improve or degrade the cooling ability of regenerative cryocoolers. For example, the thermal expansion coefficient multiplied by temperature peaks near 9 K, resulting in less enthalpy flow down the regenerator and locally improved cooling power. The same product starts to rapidly decrease below 6 or 7 K, and local cooling power instead drops. Such dramatic changes in properties over small ranges of temperature are a potential mechanism for temperature instability, where if one portion of the regenerator is at a slightly different temperature than another, the local differences in cooling power may overcome stabilizing processes (e.g. heat conduction) and grow into a large temperature asymmetry. Using a densely-instrumented, commercial 4 K pulse tube refrigerator, we have measured temperature differences of up to 19 K across the diameter of a 3 cm diameter, second-stage regenerator. These large azimuthal temperature asymmetries can appear and disappear over small changes in end conditions (e.g. with only 0.1 K changes in cold end temperature) but do so in a predictable manner related to real fluid properties. We propose stability criteria that may govern the temperature asymmetries. We also consider the instability's effect on cooling power at the cold end and at intermediate positions along the second-stage regenerator.