Modeling, Optimization, and Experimentation with a Two Stage Mixed Gas Cascaded Joule Thomson Cryoprobe

Cryosurgery is a technique for destroying undesirable tissue such as cancers using a freezing process. Cryosurgery is used to ablate prostate and liver cancer tumors and it is also used in a variety of procedures in dermatology, gynecology, and cardiology. Typical cryosurgeries last between a few minutes to an hour. Cryosurgery relies on some type of cryosurgical probe that is inserted into the body in order to create the necessary cryogenic temperatures; the cryoprobe tip reaches approximately 150-180 K for most procedures. The cryolesion that is formed is typically on the order of tens of millimeters in diameter and the lethal zone (i.e., the region in which cell death is complete) extends outward into the tissue from the cryoprobe tip approximately to the location where the tissue is about 240 K, although this will vary by ±15 K depending on the surgical details including the type and location of the procedure.

A two-stage Mixed Gas Joule Thomson (MGJT) cycle is capable of providing compact cooling for cryoprobes and is the focus of this project. The system is shown schematically in Figure 1; a conventional vapor compression (VC) cycle labeled "1st stage" provides precooling for a MGJT cycle labeled "2nd stage". A computational model of a commercially available two stage MGJT cryoprobe donated by American Medical Systems (AMS) has been developed. The model captures the fundamental thermodynamic cycle and was used to investigate optimal mixture compositions and operating conditions for MGJT cryoprobes. Selecting gas mixtures is not a trivial process as the optimal composition changes with numerous parameters including the amount of precooling, the cryoprobe tip temperature, operation pressures, and mixture constituents. The model subsequently represents a significant advance as a cryoprobe design tool for rapidly identifying optimal mixture compositions and operating parameters.

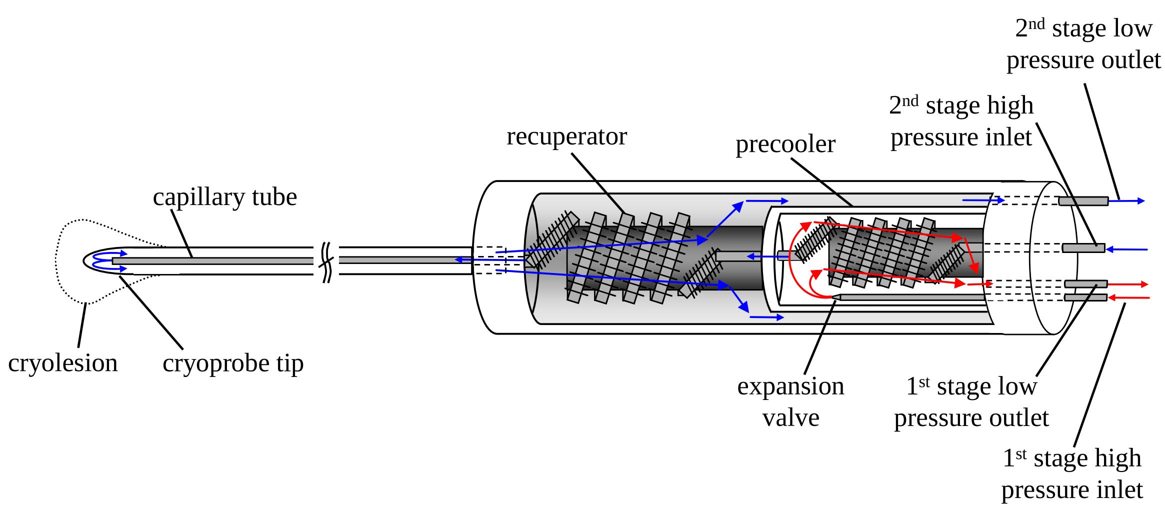

Figure 1. Geometric schematic of a 2-stage cryoprobe showing primary components and fluid flow paths.

An experimental test facility has been designed to test the performance of the system with the new, optimized mixtures selected using the model. A commercially available cryoprobe system has been modified to record measurements at key locations which capture the cryoprobe performance. The refrigeration capacity of the cryoprobe is measured by applying a precisely known amount of heat to the flow stream where the cryoprobe normally provides cooling for the surgery. Temperatures, pressures, and mass flows are measured at various locations to identify thermodynamic states and calculate heat and work transfer rates.