The Modelling and Design of an MRI-Compatible Cryosurgical Probe

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Motivation

- X-Ray mammography is the most common breast cancer imaging technique, but is 60% less effective when compared to MRI
- Combining MRI with cryosurgery could result in a more effective breast cancer treatment

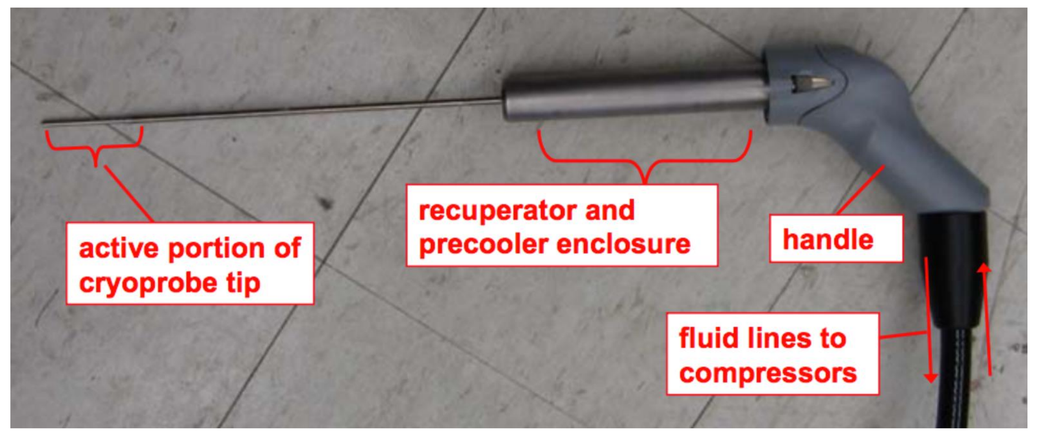
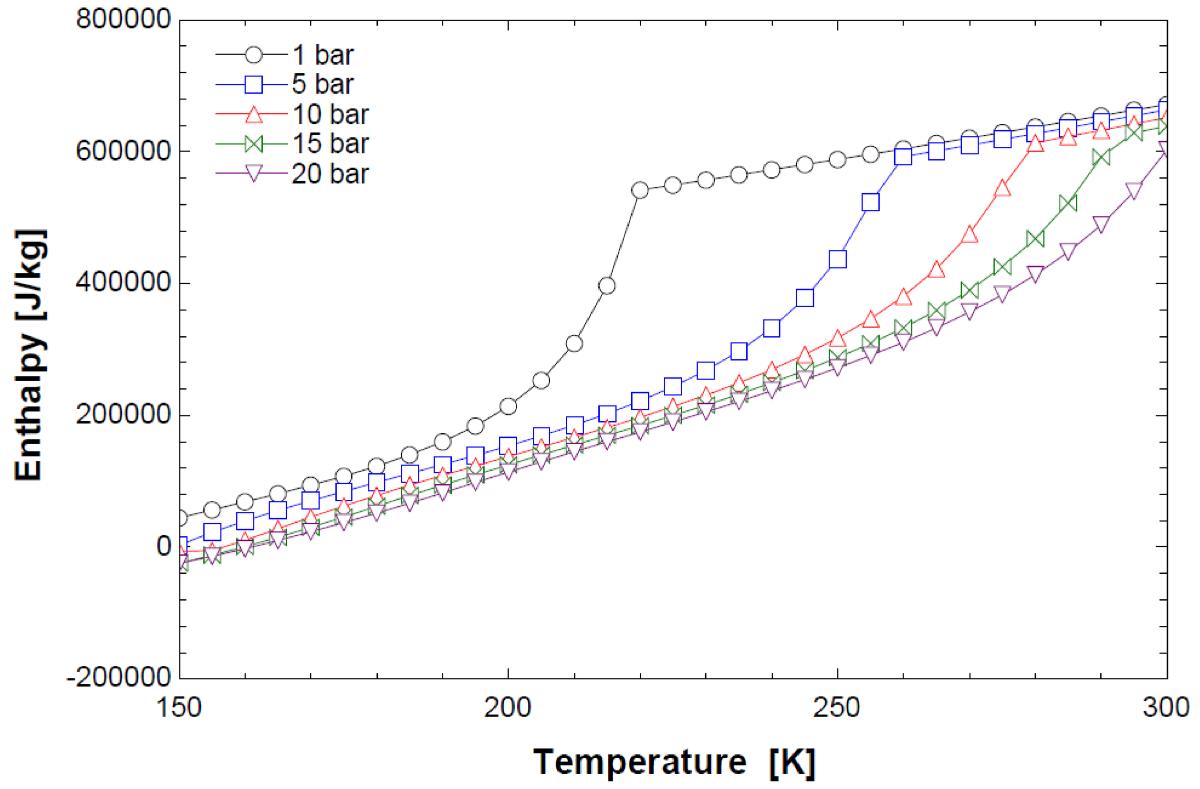


Photo of a cryosurgical probe

Gas Mixture Properties

- Property data from REFPROP for various pressures
- Interpolation for properties using temperature and pressure
- Viscosity and conductivity calculated using the two-phase volume fraction



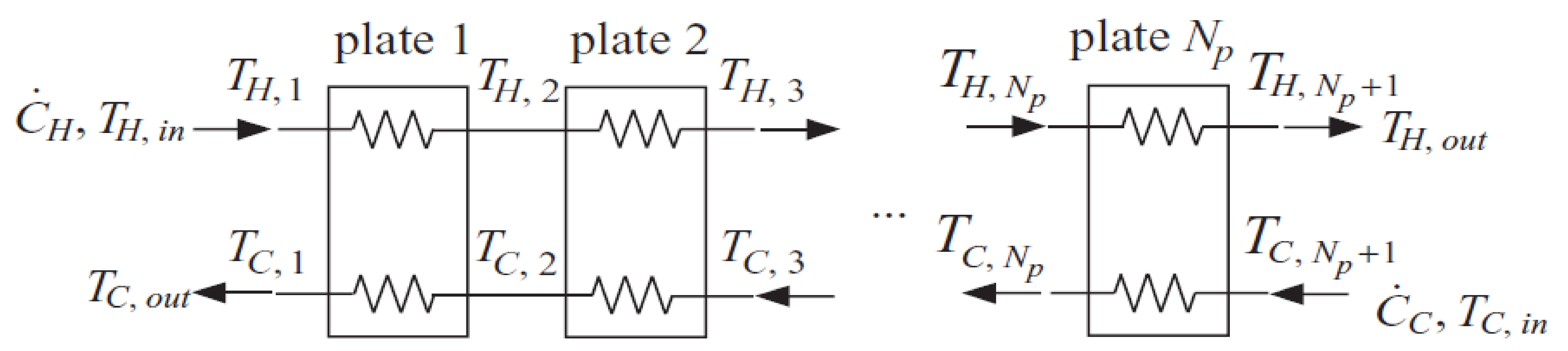
Specific enthalpy data generated from REFPROP for the optimized gas mixture

Gas Mixture Optimization:

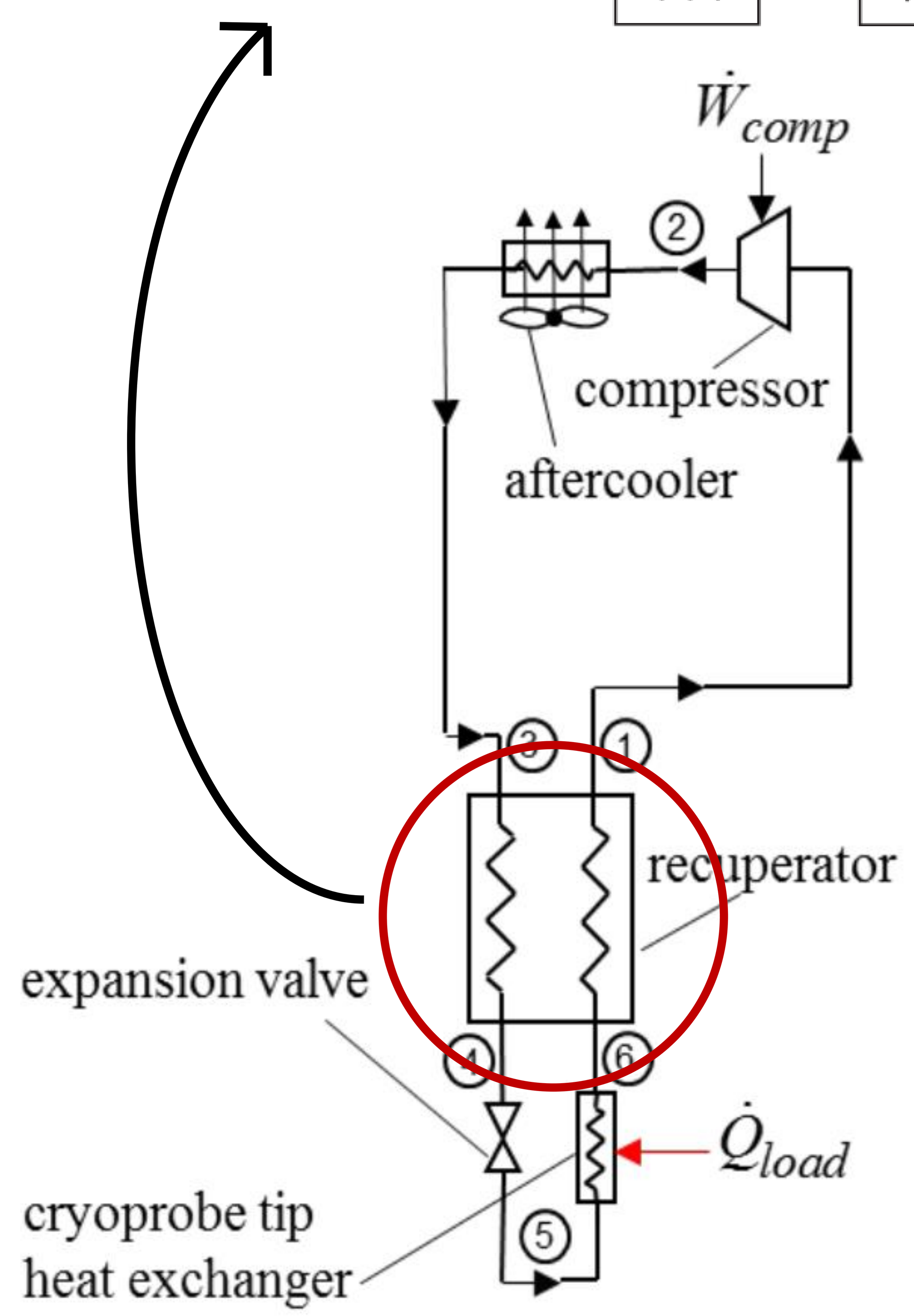
- Optimized for the operating pressures and temperature range
- Maximum minimum isothermal enthalpy change → Results in the best cooling capacity

$$0.6C_3H_8 + 0.36CH_4 + 0.04N_2$$

Thermodynamic Modelling



Visualization of heat exchanger discretization



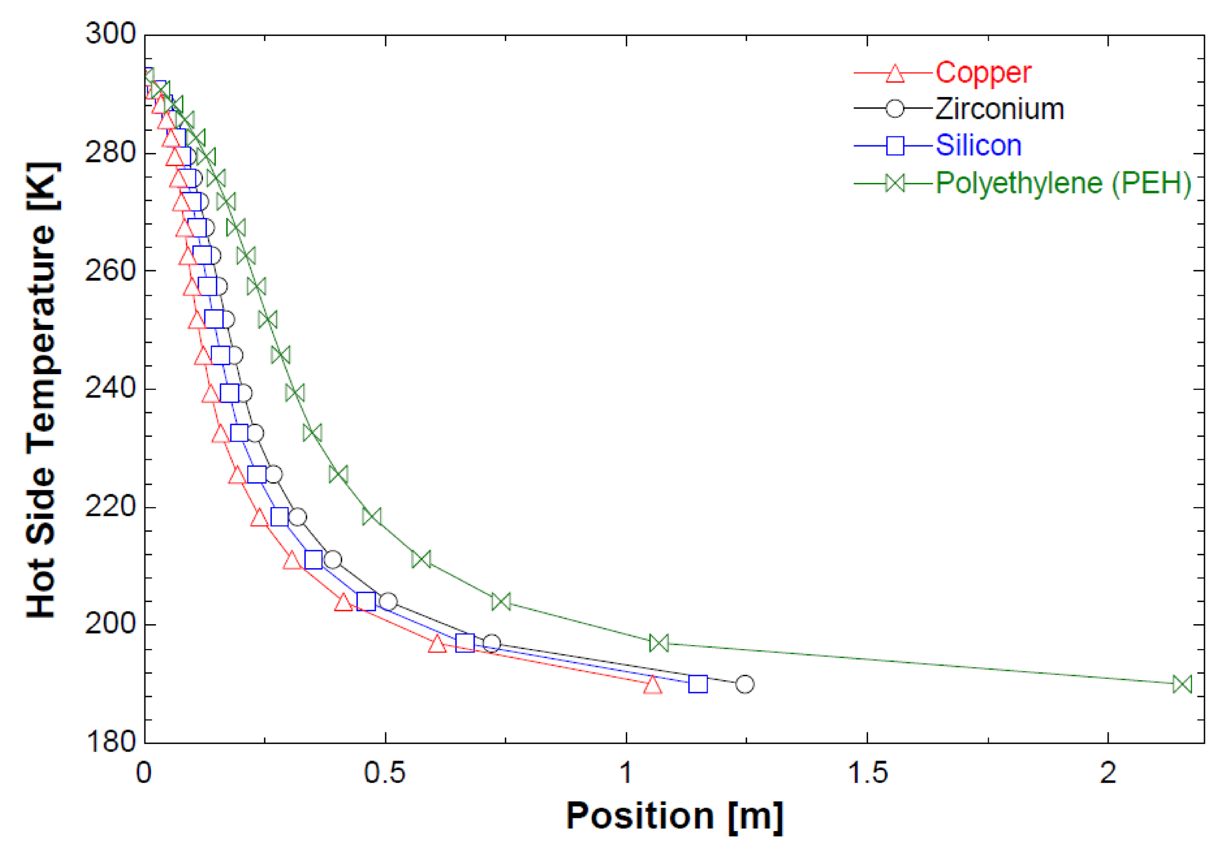
Schematic of a JT cryoprobe

Model Features:

- Discretized heat exchanger
- Axial conduction parameter
- Two-phase flow correlations
- Gas mixture properties

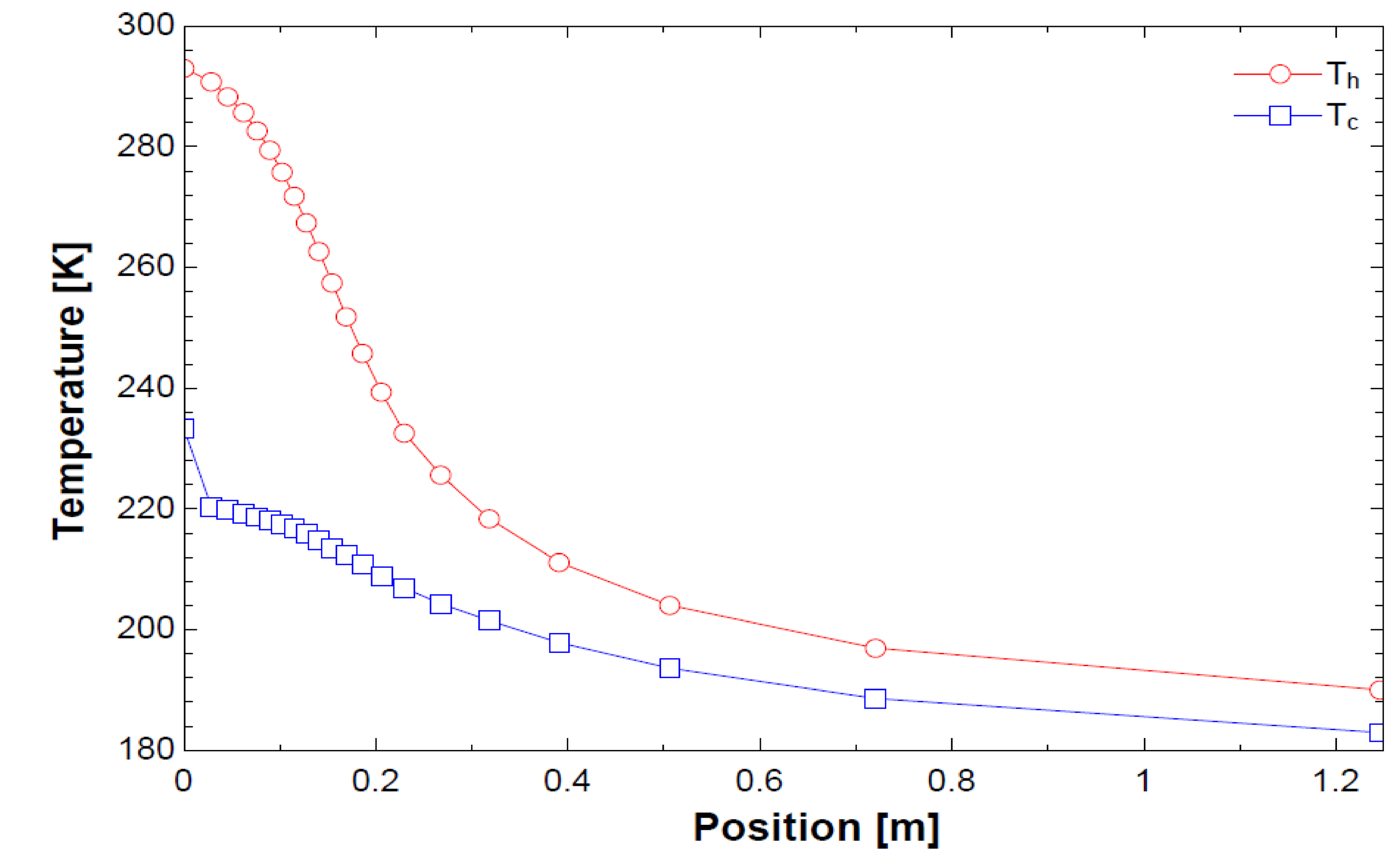
$T_{h,i}$ and $T_{c,i}$ known $\Rightarrow R_t \Rightarrow UA \Rightarrow NTU \Rightarrow \varepsilon \Rightarrow q \Rightarrow T_o$

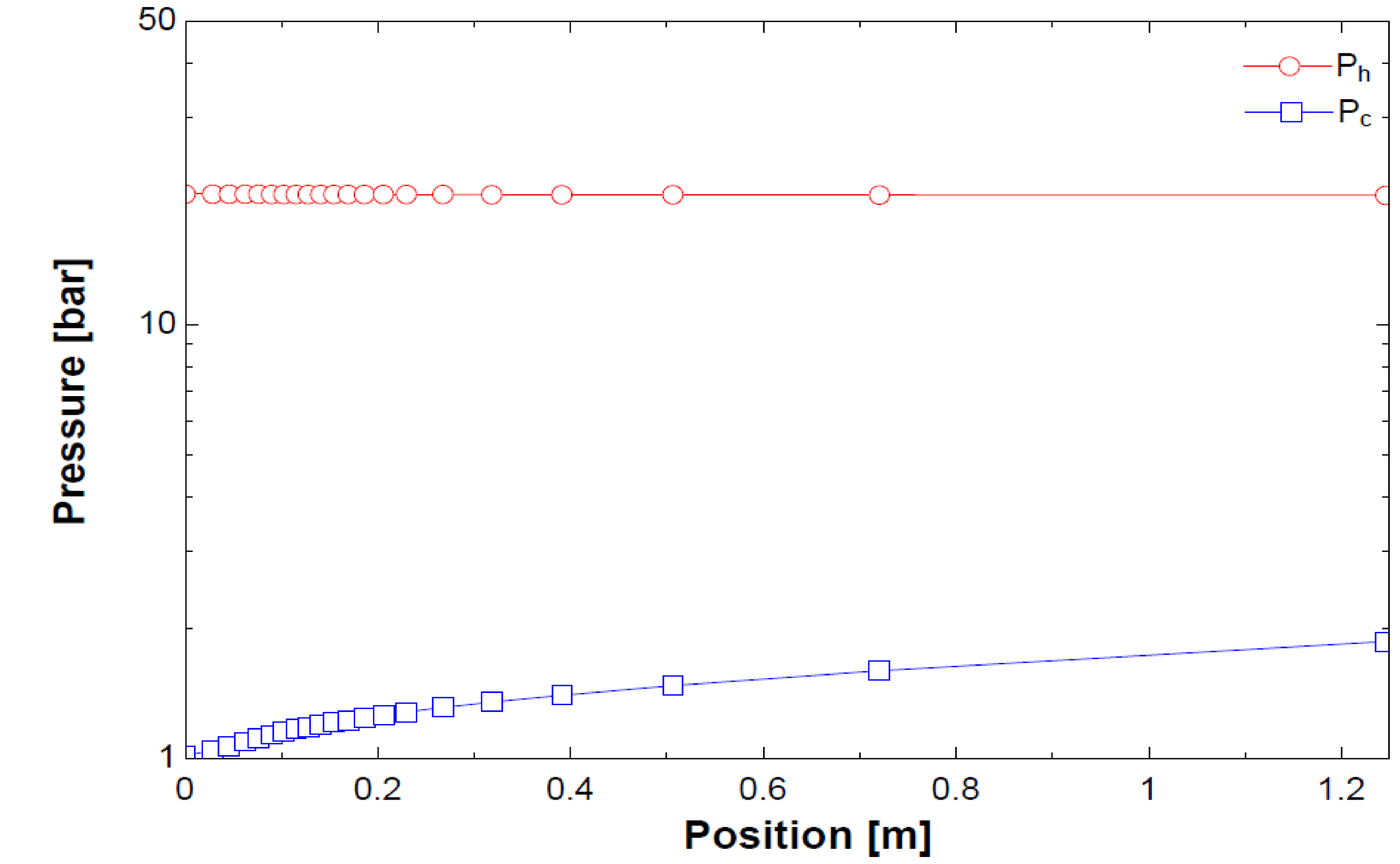
- A cryoprobe within an MRI must be non-metallic
- Modelling results suggest that a material with high thermal conductivity is desired



Material dependent heat exchanger hot-side cool down, showing the length required to reach 190 K

Results





Temperature and pressure profiles generated by the model

Input Parameters:

$N = 20$	$D_{inner} = 1$ mm	$D_{outer} = 2$ mm
$P_{in} = 2000000$ Pa	$P_{out} = 101325$ Pa	
$T_{h,in} = 293$ K	$T_{h,out} = 190$ K	

Results:

$\dot{q}_{cool} = 10$ W	$\dot{m} = 0.2$ g/s	$L_{straight} = 49.2$ in
$L_{helix} = 6.4$ in		

Conclusions

With an optimized gas mixture, an MRI-compatible cryoprobe can deliver 10 W of cooling power at 170 K while remaining a reasonable size. Heat exchanger model includes two-phase flow correlations for mixtures.

Future Work:

- Optimize heat exchanger geometry
- Generate hydrocarbon-free optimized gas mixture