FURTHER EXPERIMENTAL WORK IN MIXED-GAS JOULE-THOMSON CRYOCOOLING

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Outline:

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2. Primary Objective of Research
3. Design Considerations for the Test Section
4. Fabrication of the Test Section
5. Experimental Measurements and Discussion
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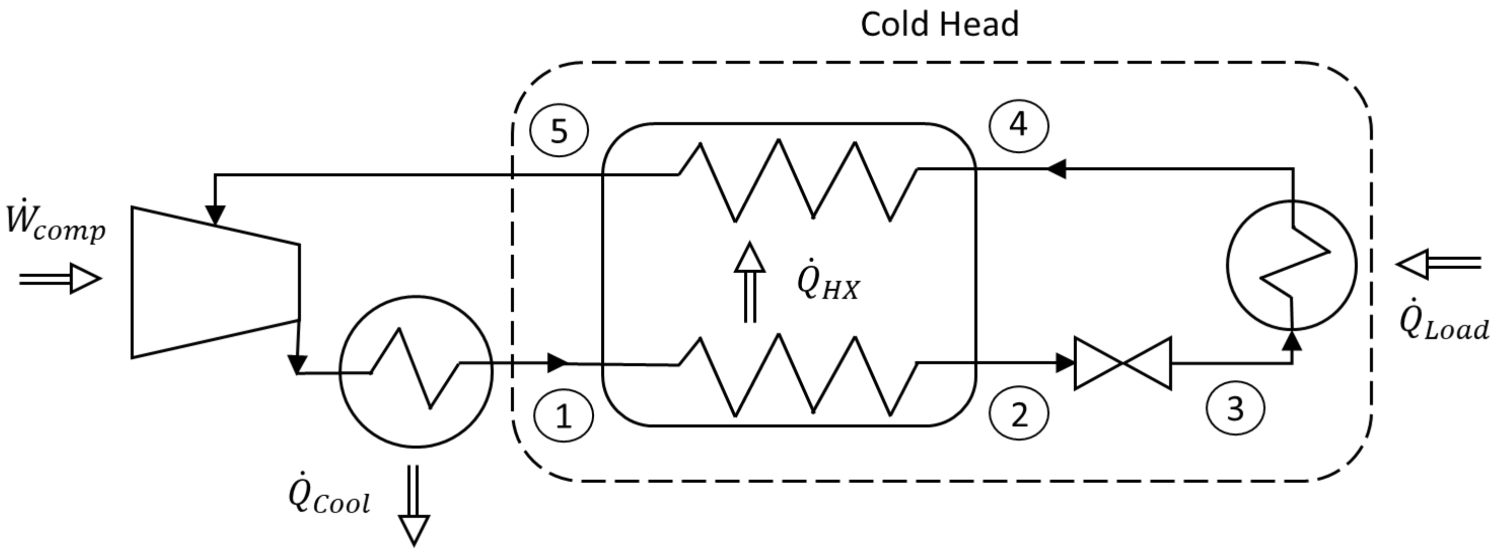
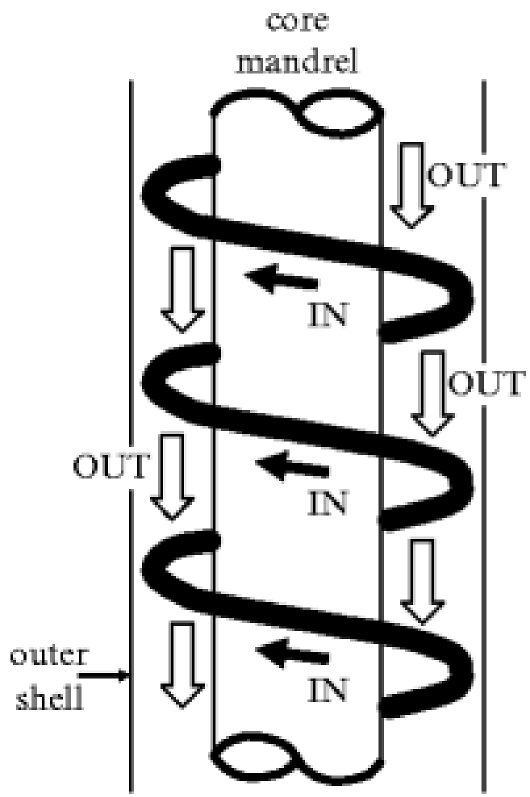
Background and Motivation:

- Recent advances increased interest in Joule-Thomson (JT) cryocoolers with cooling potential from 125 to 150 K
- To achieve high efficiency and use a low-cost compressor, must provide cooling at low pressure ratios and values of operating pressures
- Under these conditions research has shown using a suitable mixed gas can provide greater cooling capacity than pure fluid

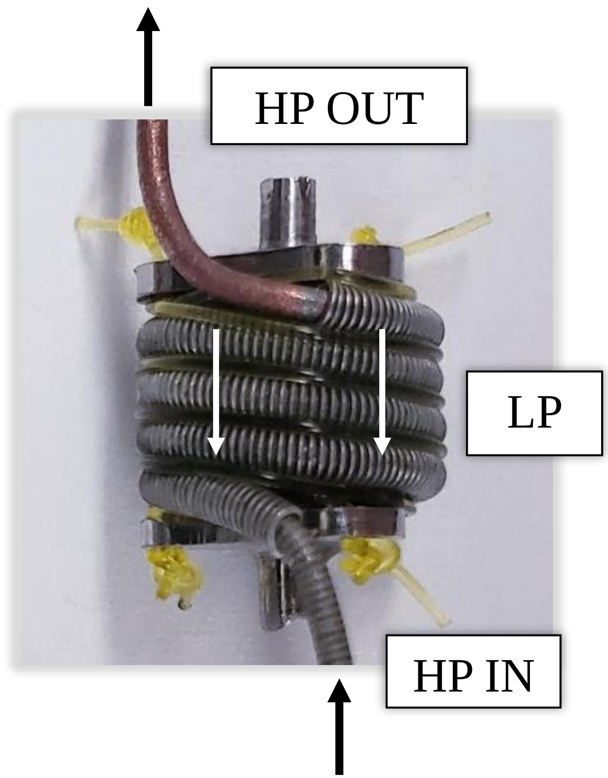


Background and Motivation:

- Coiled Finned-tube heat exchangers are most widely used hx for miniature JT cryocoolers (also known as Giauque-Hampson hx)

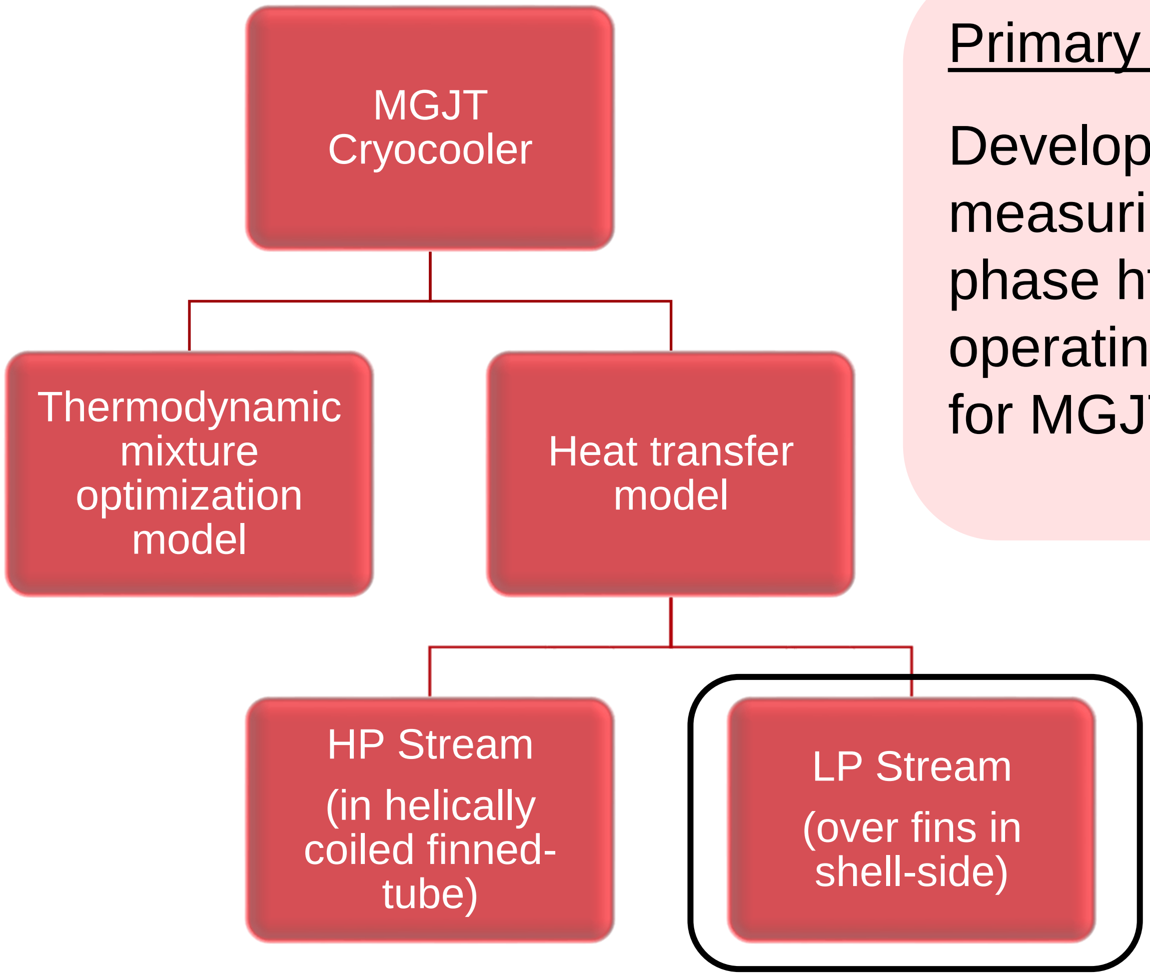


Illustration



Photo

Background and Motivation:



Primary research objective:

Develop test facility capable of measuring the shell-side two-phase htc for GH hx at operating conditions of interest for MGJT cryocooling

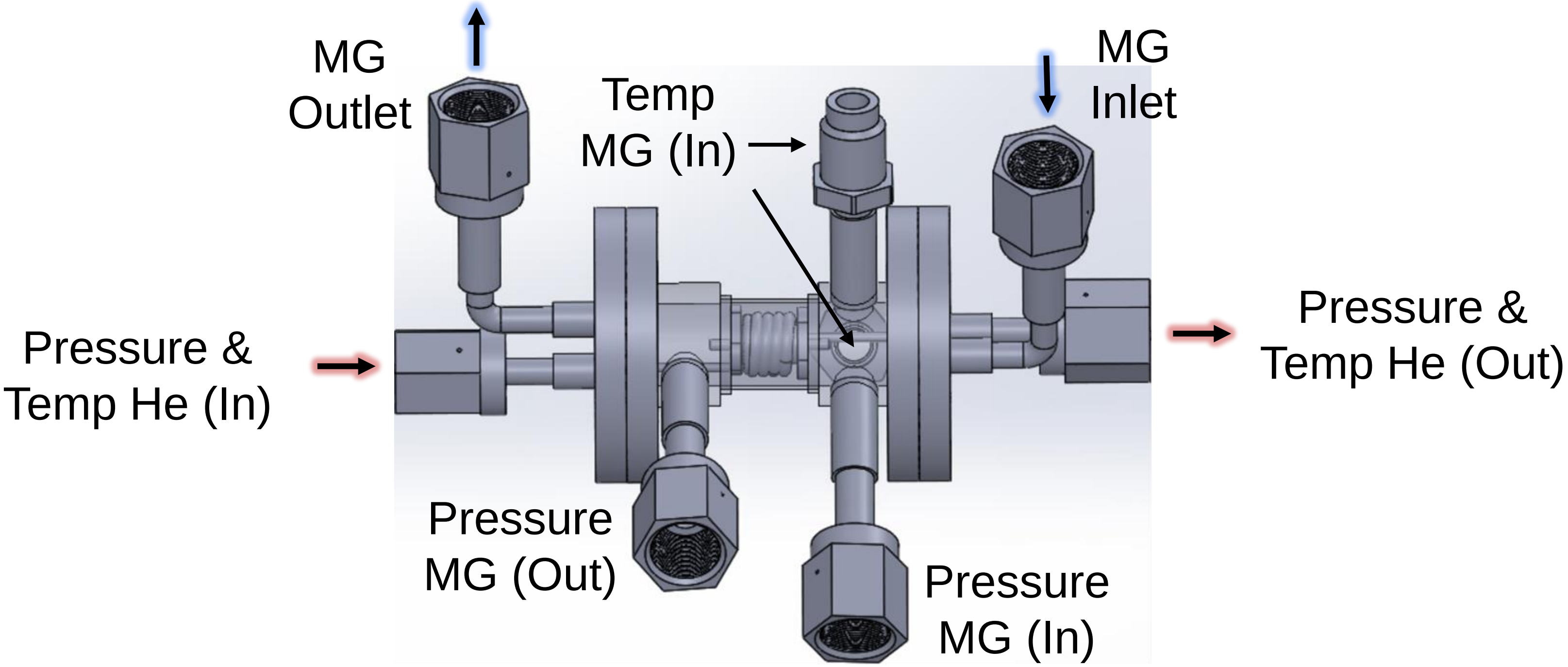
Primary Objective of Research

- Develop test facility capable of measuring shell-side h_{mg} of GH hx at operating conditions of interest for MGJT cryocooling

Operating Parameter	Value
Inlet temperature of MG ($T_{in,mg}$)	110-300 K
Mass flow rate of MG ($\dot{m}_{mg}$)	0.05-0.15 g/s
Inlet pressure of MG ($P_{in,mg}$)	345-862 kPa (50-125 psi)
Inlet pressure of He ($P_{in,he}$)	862 kPa (125 psia)
Operating fluid	Range of gas mixtures composed of Ar, butane, ethane, methane, R14, R23, R32 and N_2

- Geometry - helically coiled finned-tube
  - -70/30 CuNi tube with D_i, D_o and D_f of 0.49, 0.97, and 1.46 mm (0.019”, 0.038” and 0.057”)
  - -Fin density of 3.94 fins per millimeter (100 fins per inch)

Design Considerations for Test Section



- Heat load is applied to gas mixture via interaction with helium in coiled finned-tube
- From measurements of flow rates and inlet and outlet conditions, conductance of hx is determined
- $\bar{h}_{he}$ is well-known and R_{he} is small from experimental set-up. Therefore h_{mg} is determined from total resistance.

Design Considerations for Test Section

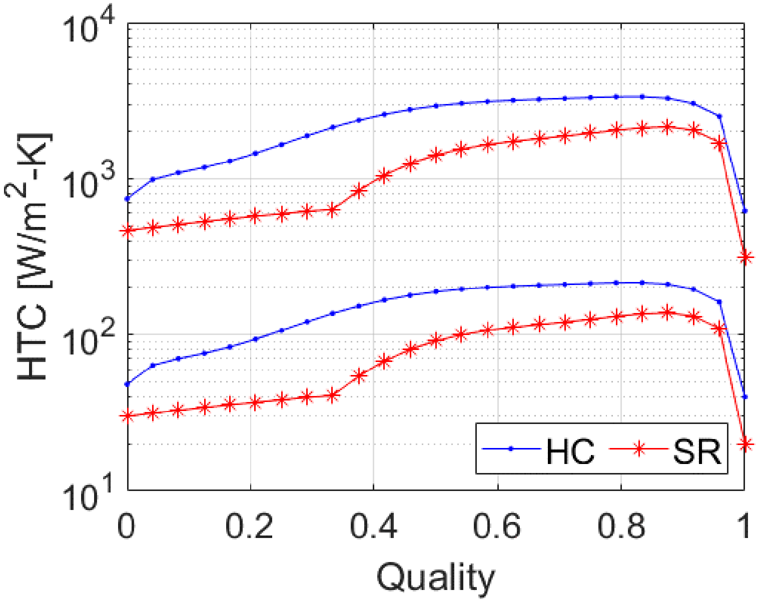
Length of Finned High-Pressure Tube

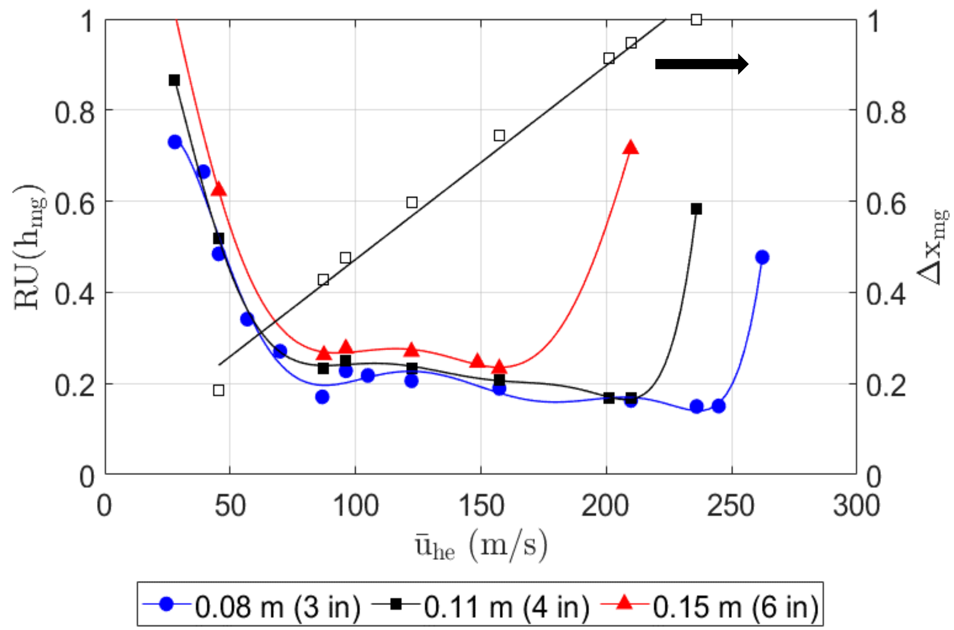
- Analysis required to understand tradeoff between the uncertainty of h_{mg} and change in quality of the mixed gas
- No correlation available to predict even the magnitude of the *htc* for two-phase multi-component mixture

1. Evaluate *htc* of pure fluid on shell-side in current design using Gupta et al.
2. Evaluate *htc* of pure fluid in horizontal tube with same dimensions and operating conditions as Barraza et al.
3. $SF = htc_{shell} / htc_{straight\ pipe}$
4. Estimate h_{mg} in shell-side of GH hx by applying SF

Design Considerations for Test Section

Length of Finned High-Pressure Tube





- Using SF, h_{mg} is predicted to fall between the very large range of 20 to 3000 W/m^2-K

- RU analyzed using greatest predicted h_{mg}
- Target helium flow rate of 85 m/s and length of 0.11 m (4 inch)

Fabrication of the Test Section

Mandrel Plugs & Mandrel

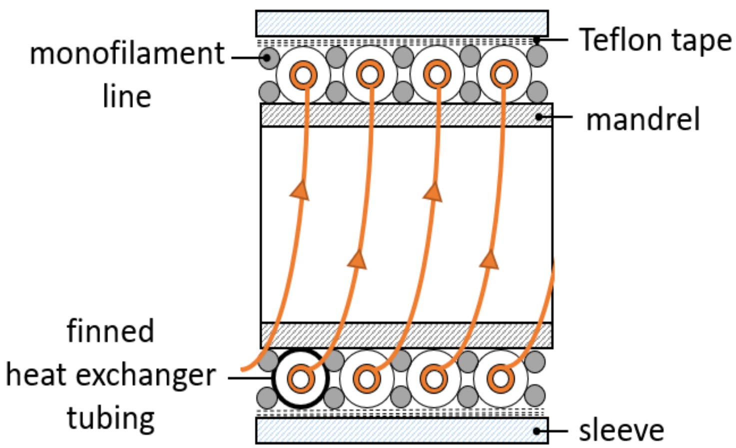


Illustration - HX Test Section

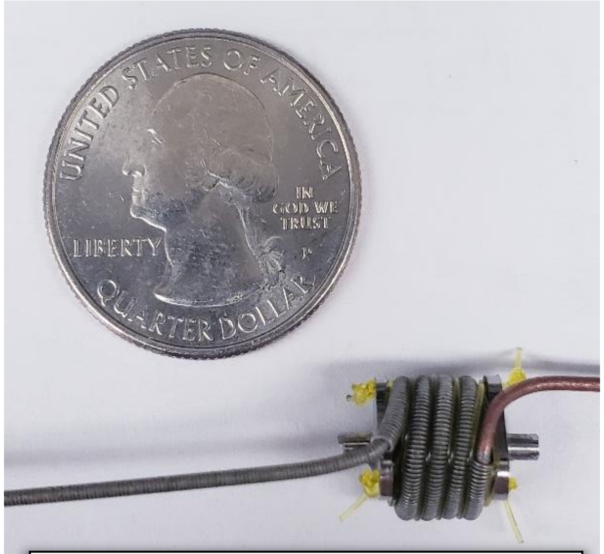
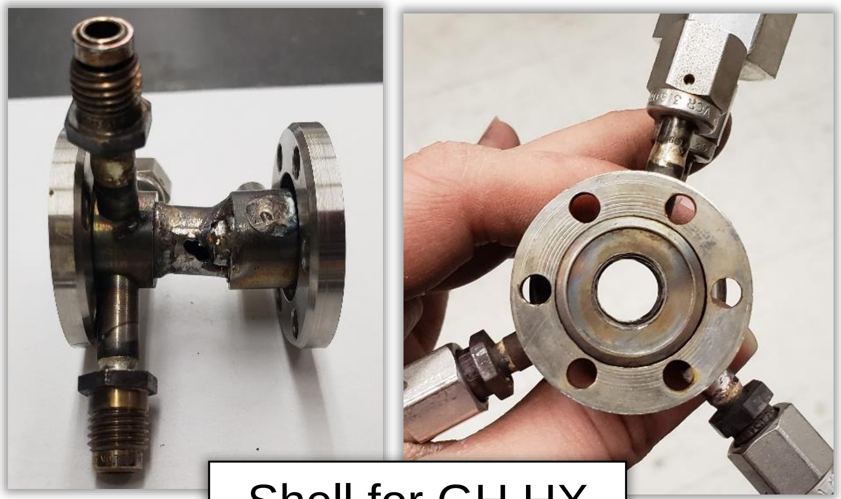


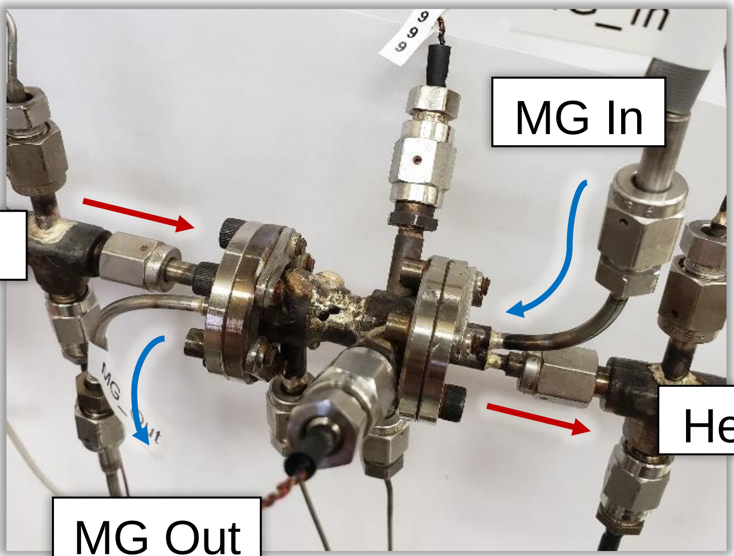
Photo - HX Test Section

Fabrication of the Test Section



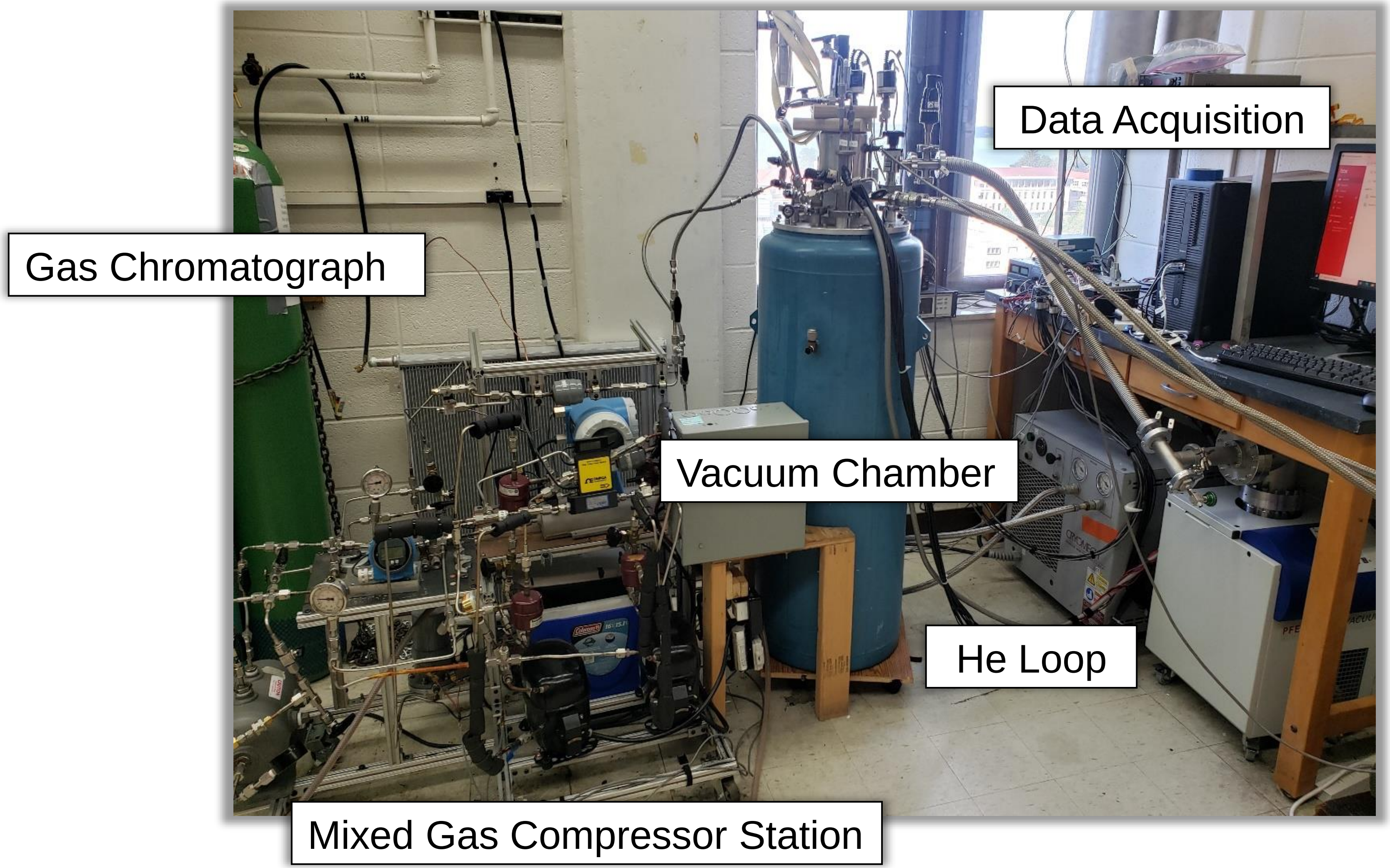
Shell for GH HX

He Entrance/Exit



Assembled Test Section

Experimental Test Facility

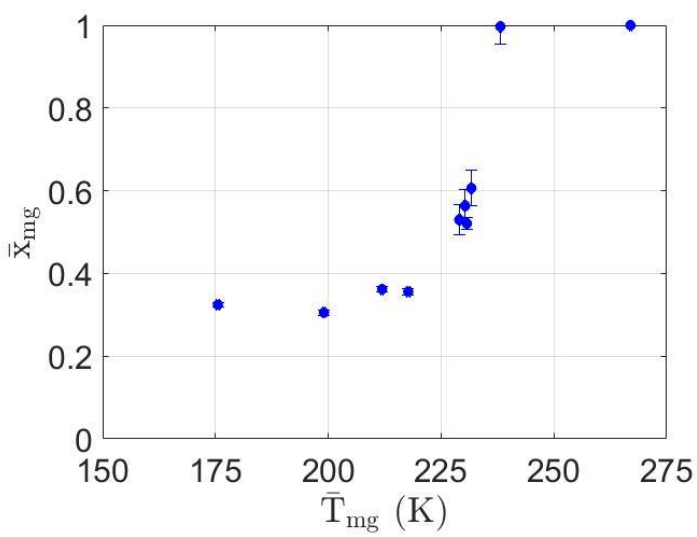


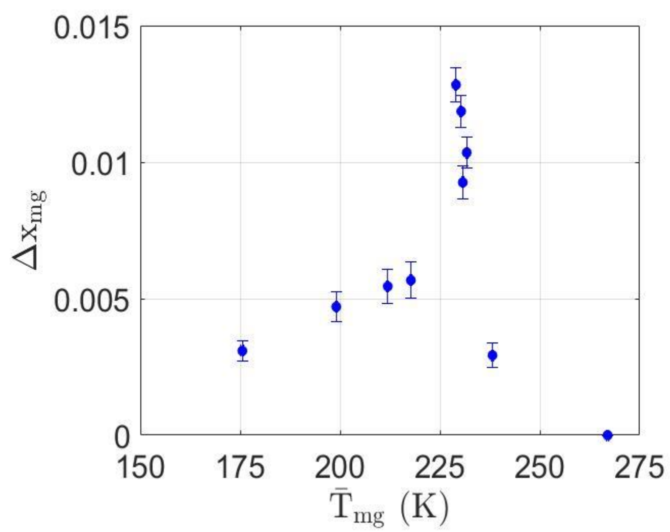
Experimental Measurements and Discussion

Operating Conditions -

	Parameter	Operating Range
Mixed Gas	Inlet Temperature, $T_{mg,in}$	174-267 K
	Inlet Pressure, $P_{mg,in}$	268-311 kPa (39-45 psi)
	Mass flow rate, $\dot{m}_{mg}$	0.15-0.16 g/s
	Molar fraction of R32	0.67-0.86
	Molar fraction of R14	0.33-0.14
Heliu m	Inlet Temperature,$T_{he,in}$	226-275 K
	Inlet Pressure, $P_{he,in}$	608-721 kPa (88-105 psi)
	Volumetric flow rate, $\dot{V}_{ref}$	0.19 L/min

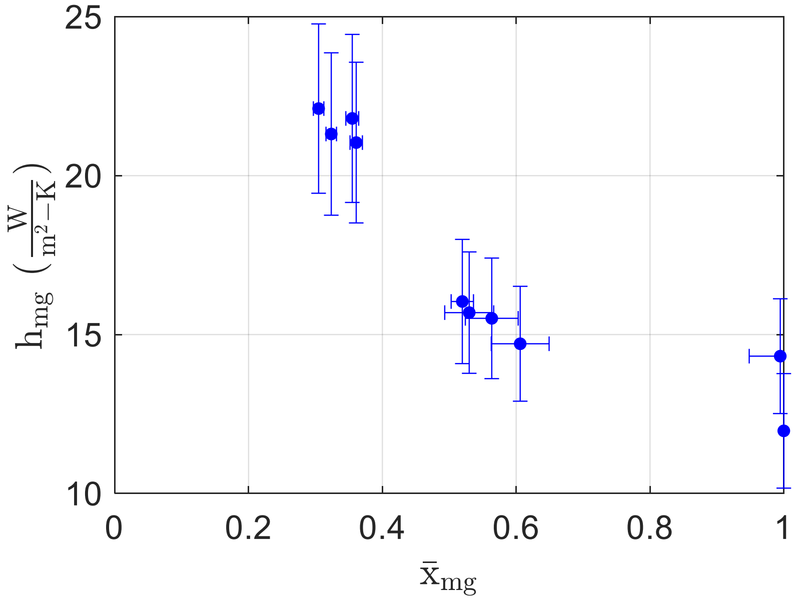
(a)





(b)

Experimental Measurements and Discussion



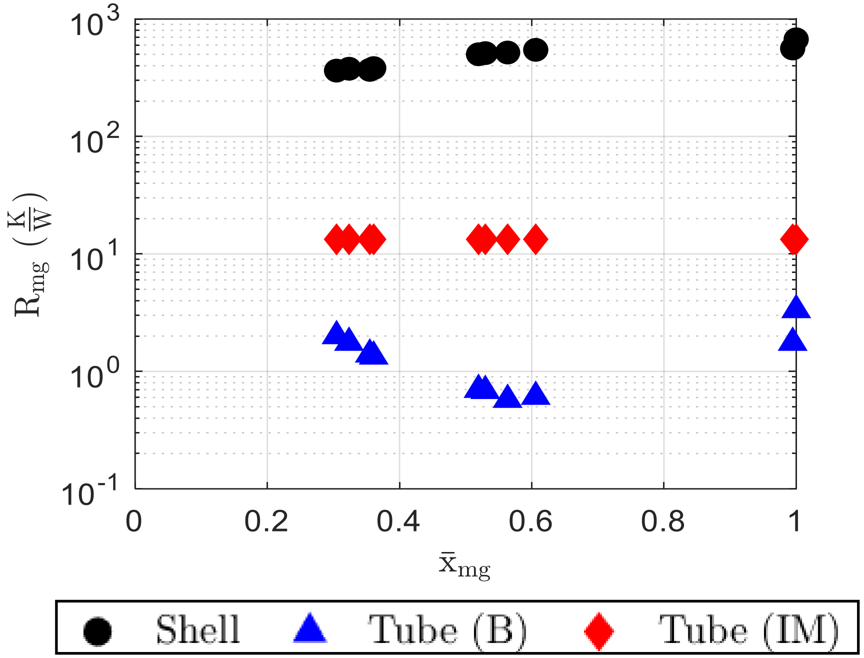
- Measured h_{mg} ranges from 12-22 W/m^2-K with uncertainties of 12-15%
- h_{mg} in two-phase region (0.32-0.61 for data collected) is increased compared to quality of 1
- Reveals that the h_{mg} may be dominant thermal resistance in hx for these flow conditions

Experimental Measurements and Discussion

Source	Correlations	Reynolds Number	Dimensions
Croft and Tebby	Single-phase pure fluid	Not reported	$D_o = 8.1\ mm\ (0.32")$ $h_f = 4.1\ mm\ (0.16")$
Gupta et al.	Single-phase pure fluid	500 < Re_f < 1900	$D_o = 11\ mm\ (0.42")$ $h_f = 1.4\ mm\ (0.06")$ $D_c = 145\ mm\ (5.7")$
Timmerhaus and Flynn	Single-phase pure fluid	400 < Re_{D_h} < 10,000	Annular-flow with helical fin from mandrel to shell
Howard et al.	Single-phase pure fluid	$100 < Re_{D_h} < 10{,}000$	$D_o = 10\ mm\ (0.38")$ $h_f = 6.4\ mm\ (0.25")$ $D_c = 143\ mm\ (5.7")$
Test Section	Two-phase multi-component mixture	$10 < Re_{D_h} < 40$	$D_o = 1.5\ mm\ (0.04")$ $h_f = 0.5\ mm\ (0.01")$ $D_c = 7.9\ mm\ (0.31")$

- Single-phase pure fluid correlations not suited for two-phase multi-component mixtures
- Reynolds number and test section dimensions are a magnitude lower

Experimental Measurements and Discussion



- Tube (B) - $R_{mg,t}$ estimated by SF from data of Barraza et al. $h_{mg,t} \approx 2000 - 14{,}000$ W/m^2-K
- Tube (IM) - $R_{mg,t}$ estimated by 75% reduction of ideal mixture $h_{mg,t} \approx 500$ W/m^2−K

- $R_{mg,s}$ is over a magnitude larger than conservative estimate of $R_{mg,t}$ and two magnitudes larger than estimate using Barraza et al.
- R_{mg} in shell is significantly larger than in helically coiled tube

Conclusions & Future Work

- Return stream in a GH hx is often neglected during JT cryocooler design
- Data collected clearly demonstrates the need for and importance of developing accurate correlations at these operating conditions
  - Offers magnitude of h_{mg}
  - Demonstrates thermal resistance of LP stream is significant
  - Provides insight to flow characteristics – indicates low velocity gas flow
- Future work includes a large test matrix for multi-component mixtures with varying geometrical parameters at operating conditions associated with MGJT cryocoolers
- With the large data campaign proposed and enabled by the test facility developed in this work, correlations can be developed

Questions?

Thank you!