Visualization of Film Condensation Onset and Microscale Cryogenic Condensate Film

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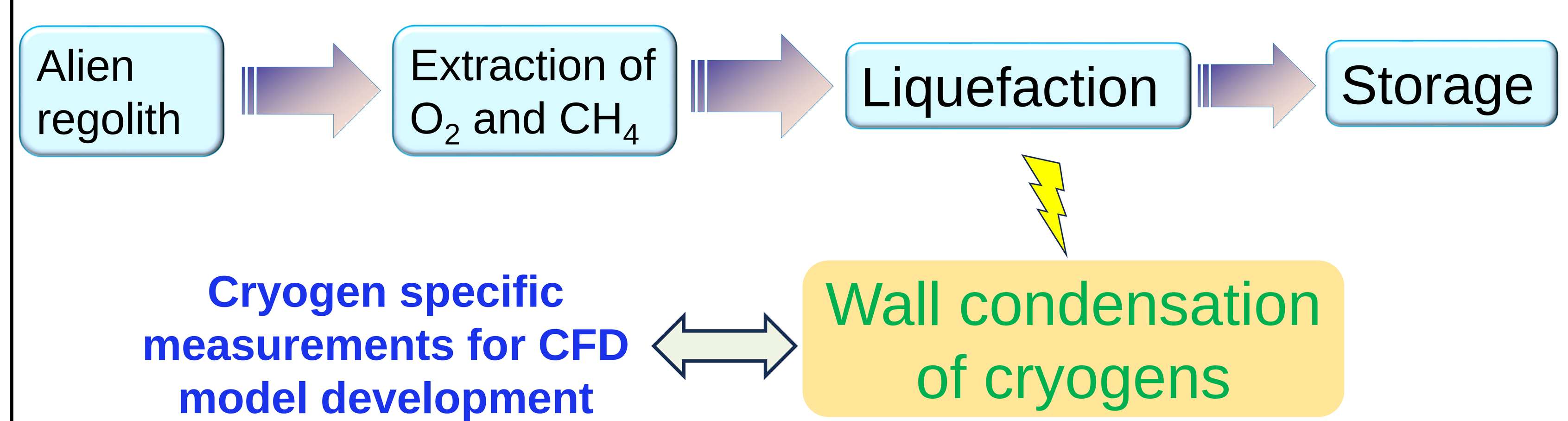
1 Introduction

- In-space Resource Utilization (ISRU) technologies are key to long-term and mass efficient lunar and mars missions[1]
- ISRU includes design of hardware/processes for recovery, **liquefaction**, transport, and storage of cryogens

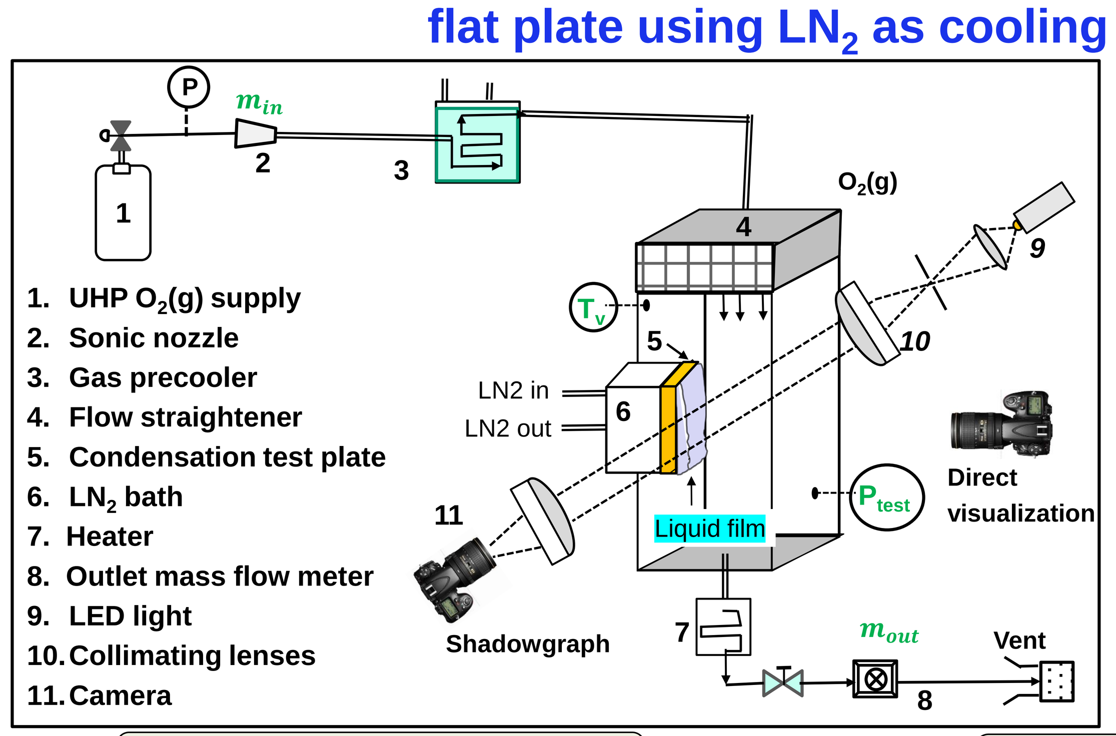


2 Research objectives

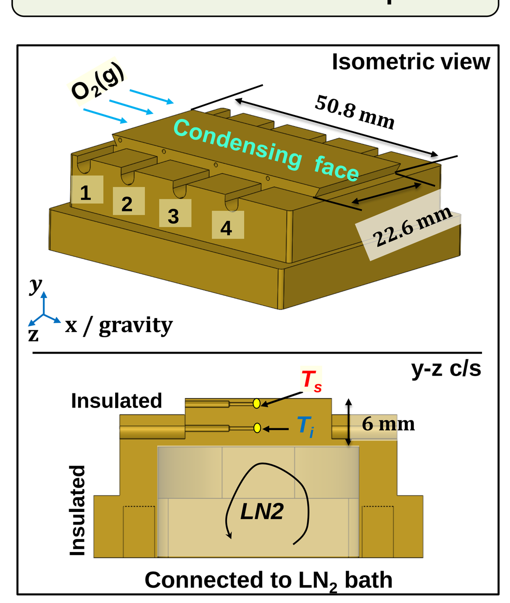
- ❑ Develop a test rig to induce wall condensation of ISRU relevant cryogens : O_2, CH_4, and N_2
- ❑ Visualization study of onset of condensation with inline process measurements
- ❑ Estimation of steady state condensate film thickness using measured heat flux and a visualization technique

3 Experimental setup

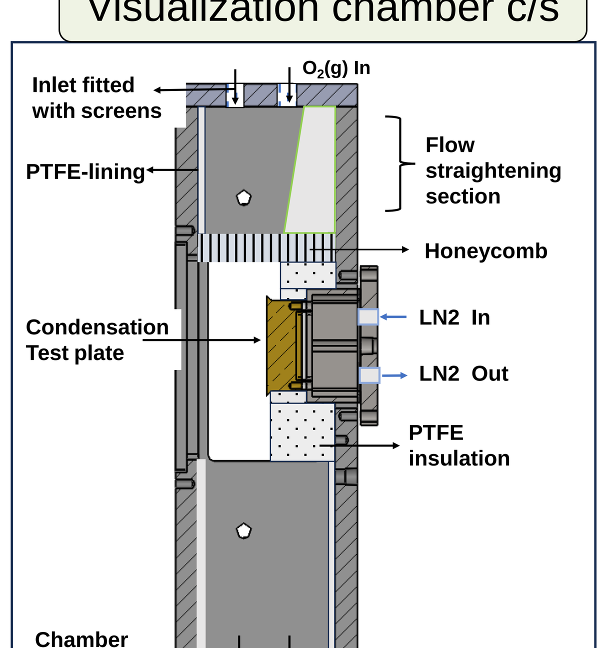
Test-rig to induce laminar film condensation of oxygen on a vertical flat plate using LN_2 as cooling media



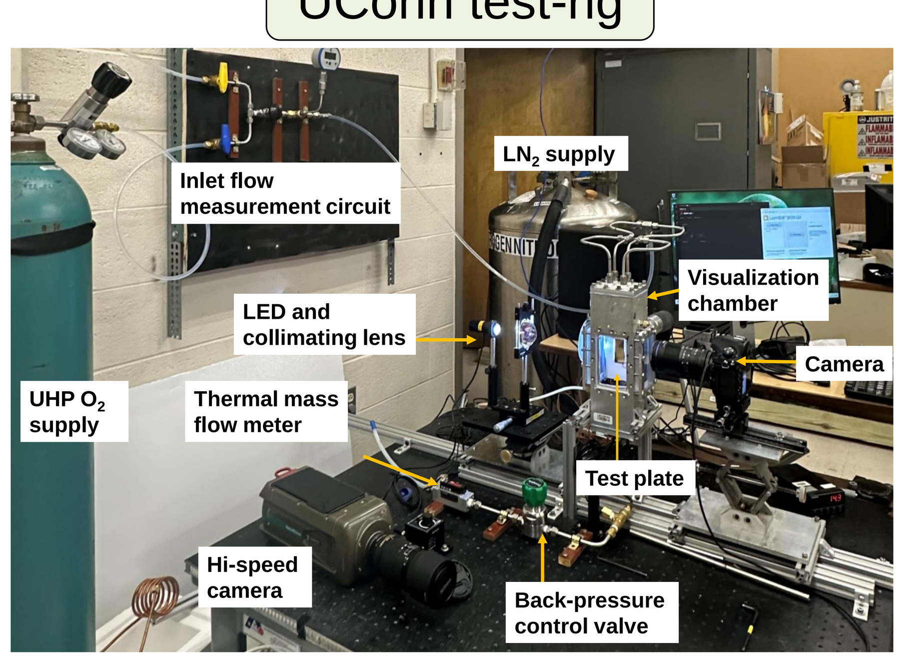
Condensation test plate



Visualization chamber c/s

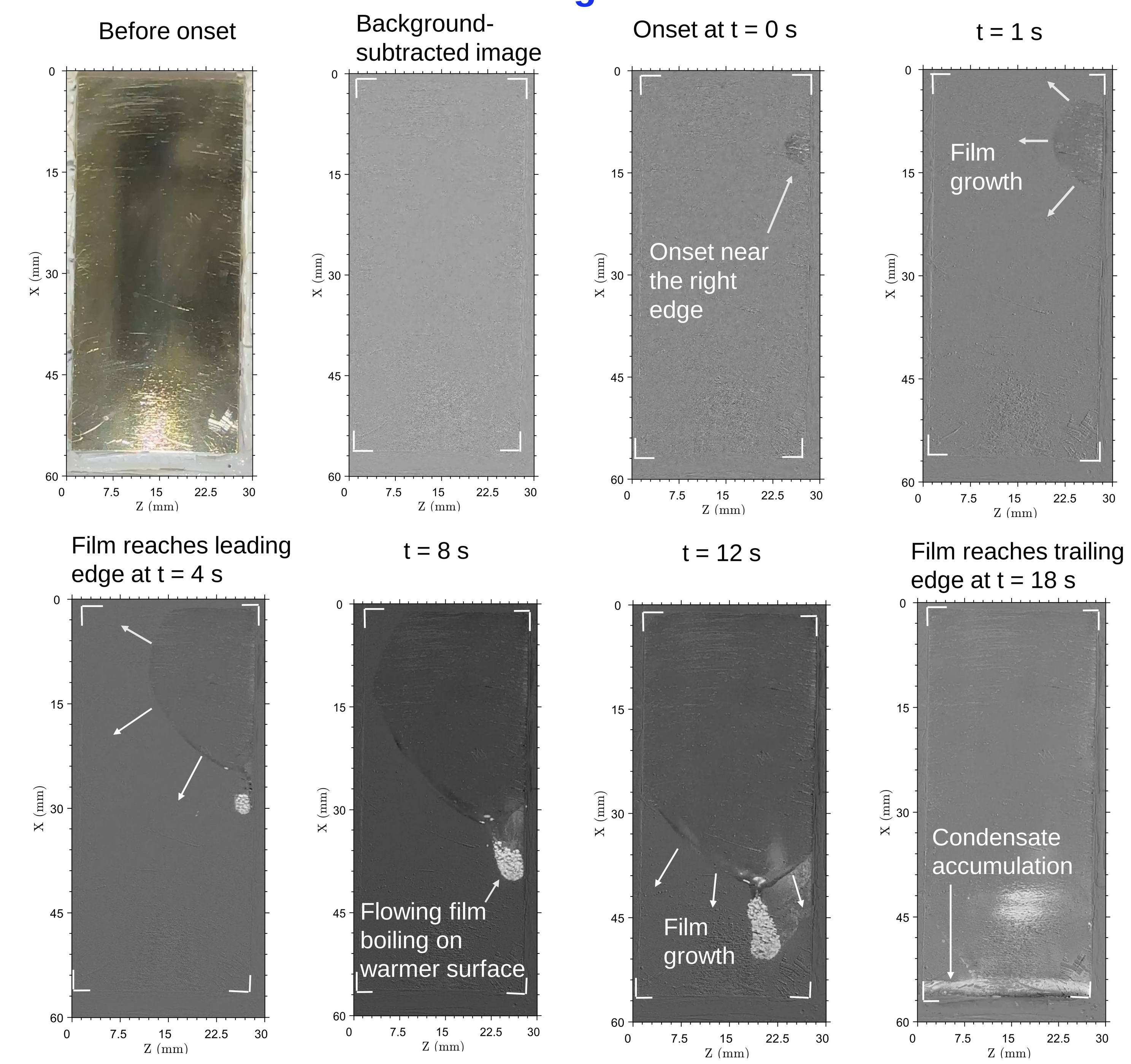


UConn test-rig

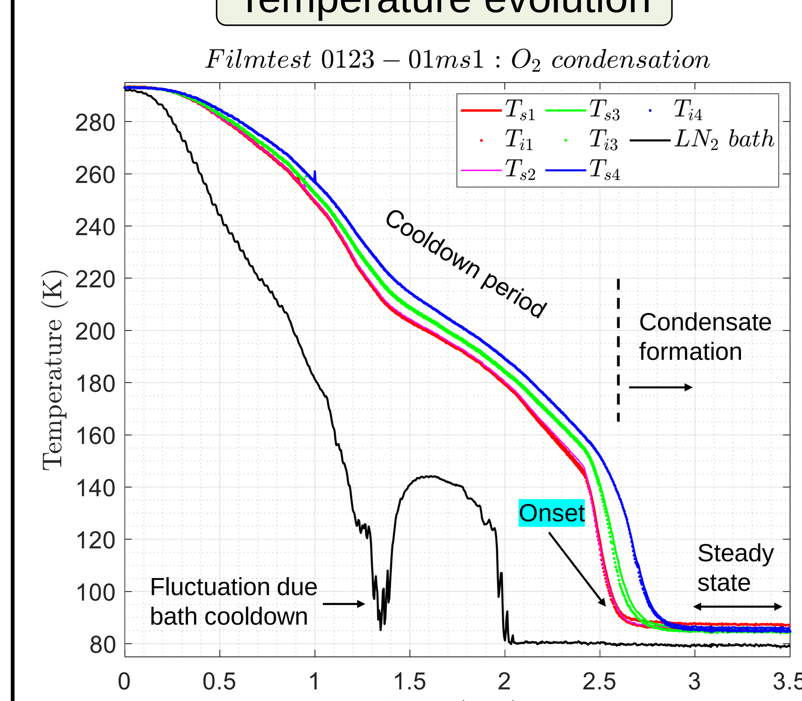


4 Results: Visualization of condensation onset

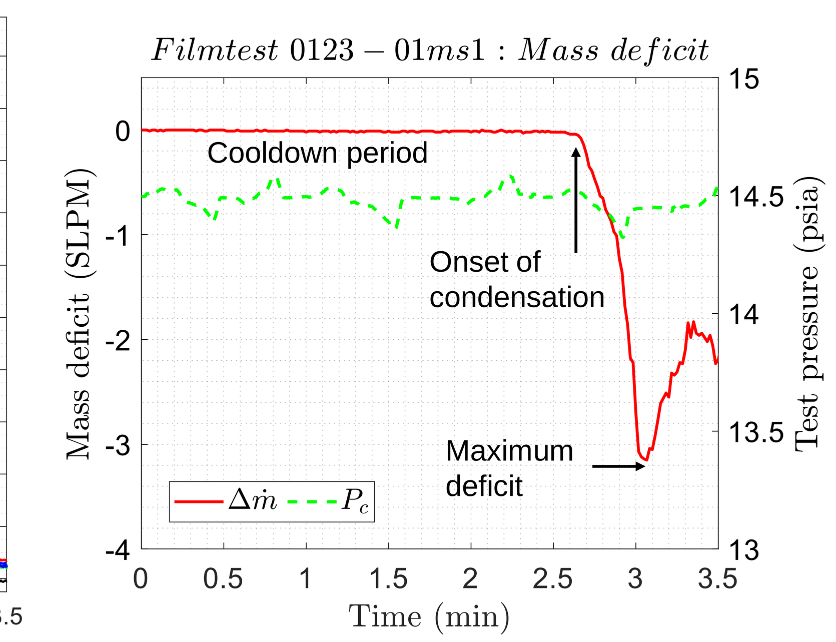
Condensate front grows from a local spherical kernel to a thin film covering entire surface



Temperature evolution



Mass deficit



Condensation onset is coupled with LN_2 bath chilldown

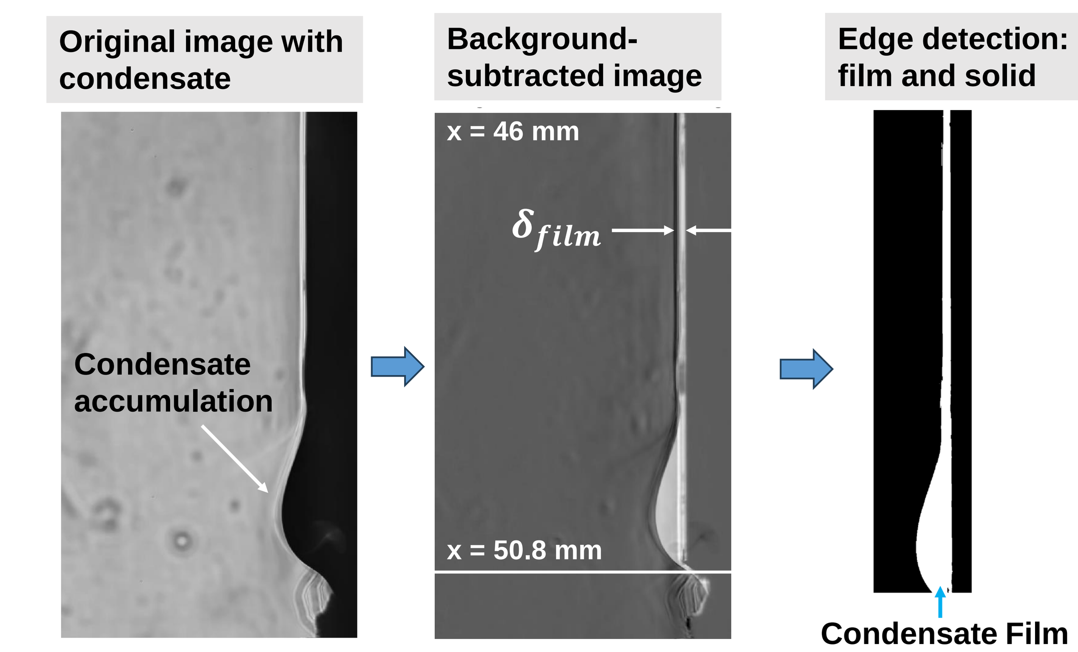
Estimated heat transfer coefficient and film thickness at steady state

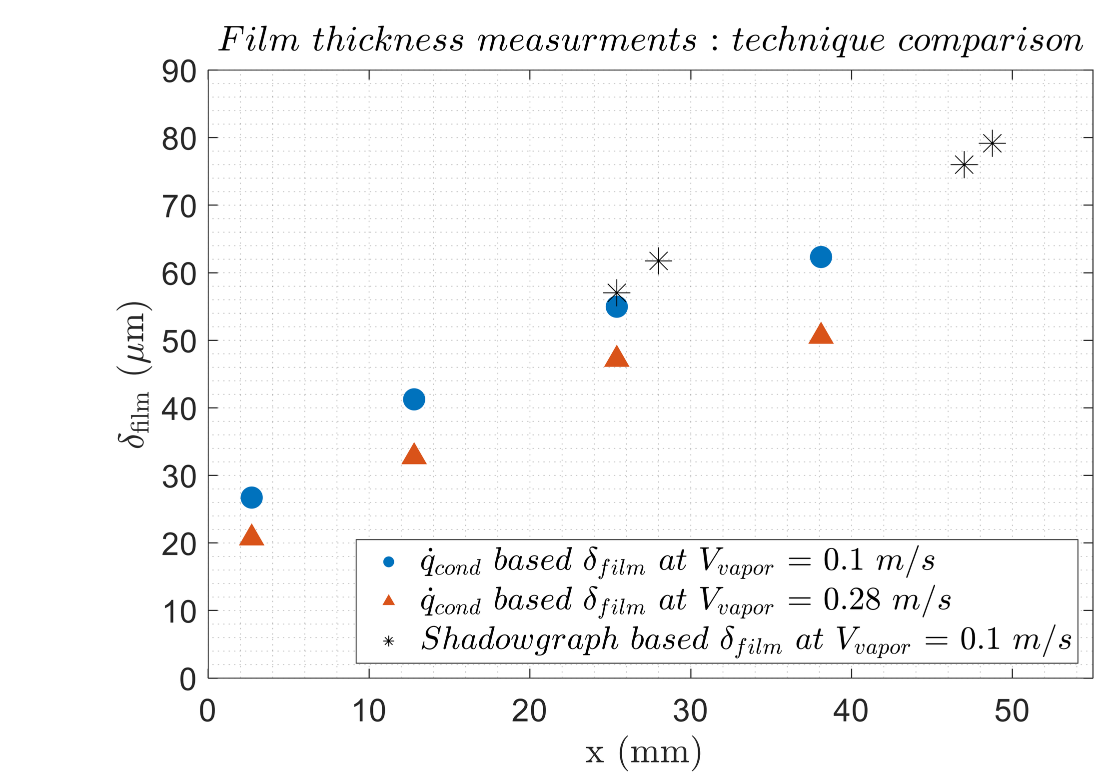
Inlet conditions	Stream wise location (mm)	Surface TC T_s(K)	Internal TC T_i(K)	HTC ($Wm^{-2}K^{-1}$)	Film thickness (µm)
V_{vapor} = 0.1 m/s	$z = 2$	$T_{s1} = 86.44$	$T_{i1} = 84.06$	7231	**21.2**
T_{vapor} = 289 K	$z = 12.7$	$T_{s2} = 85.13$	$T_{i2} = 83.27$	4094	**37.8**
P_{test} = 14.5 psia	$z = 25.4$	$T_{s3} = 85.08$	$T_{i3} = 83.73$	2949	**52.4**
	$z = 38.1$	$T_{s4} = 85.08$	$T_{i4} = 83.95$	2486	**62.2**

LOx laminar condensate film is of microscale thickness

5 Results: Film thickness visualization

Film thickness is extracted from high-resolution shadowgraph





Shadowgraph technique capture microscale LOx condensate film thickness

6 Conclusions and future work

- ✓ Test-rig is developed to induce condensation of cryogen vapor using LN_2 as cooling media. Visualization of condensation phenomena and film thickness measurement are conducted
- ✓ Onset of condensation occurs at local cold spot. Condensation front forms and grows as a spherical kernel initially. As the condensate mass builds up, gravity causes flow of condensate
- ✓ Steady state film thickness measurement shows microscale nature of formed condensate film for cryogens
- ✓ High resolution shadowgraph technique is developed for film thickness measurement. Measurement of film thickness using visualization-based technique compares well with heat flux-based estimation

Future work
- Parametric studies: Impact of wall temperature and orientation on condensation phenomena
- Computational modelling of condensation of cryogens

7 References

1. Johnson et al. (2018). Comparison of oxygen liquefaction methods for use on the Martian surface. *Cryogenics*, *90*, 60-69.
2. Settles, G. S. (2001). Schlieren and shadowgraph techniques: Visualizing phenomena in transparent media. Springer Science & Business Media.

Acknowledgment

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