80 K vibration-free cooler for potential future Earth Observation missions

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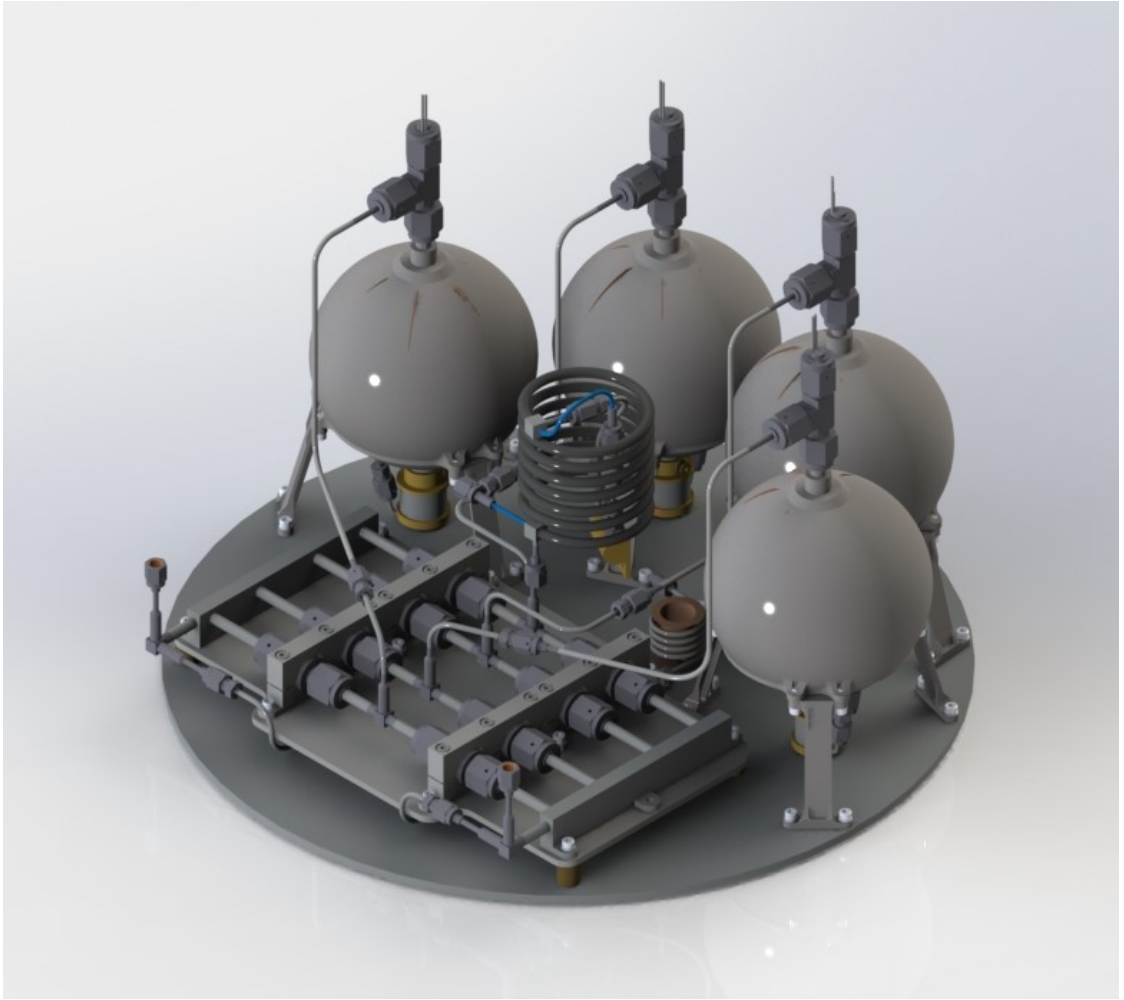
Overview

- Objectives
- 80 K Vibration-free cooler
  - Proposed solution/design
- Sorption Compressor
  - Working Principle
  - Sorbent Materials
  - Gas-Gap Heat Switch (GGHS)
- Conclusions



80 K Vibration-free cooler (render)

Objectives

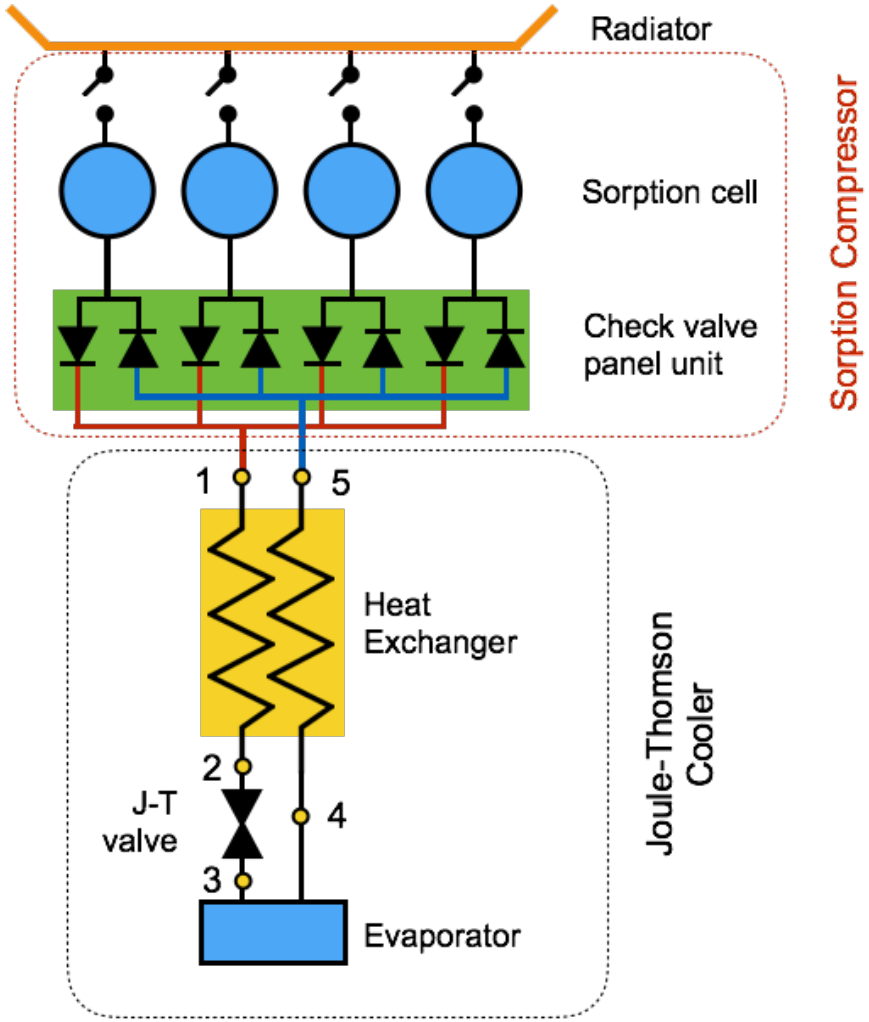
Design, manufacture and test an Elegant Breadboard Model of a "Vibration-Free" cooler for potential future Earth Observation IR missions

Main requirements

- Functional point @ **80 K**
  - Cooling Power **1000 – 1500 mW**
- **Radiator area:** <1.5m^2
  - Radiating at 90 K
- Temp. stability: < 100 mK/15 min
- Lifetime: >5 years (goal 10 years)
- Power budget: 180 W

80 K Vibration-free cooler

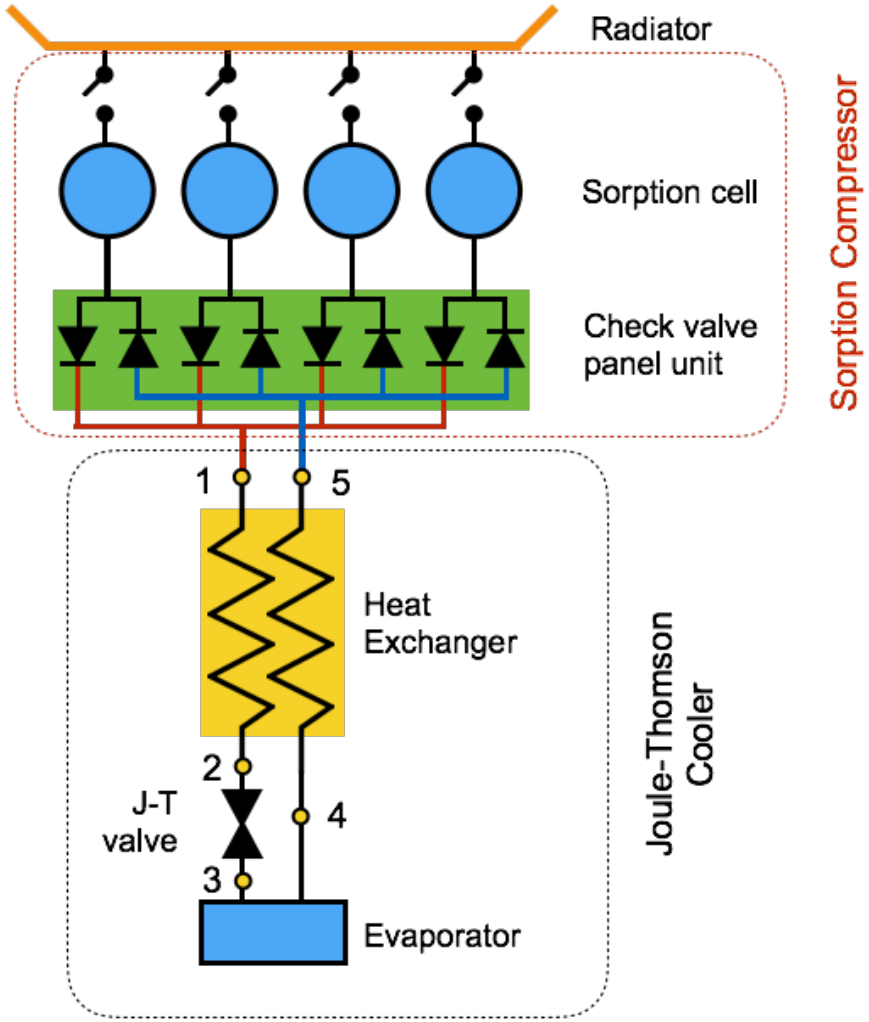
Proposed design/solution



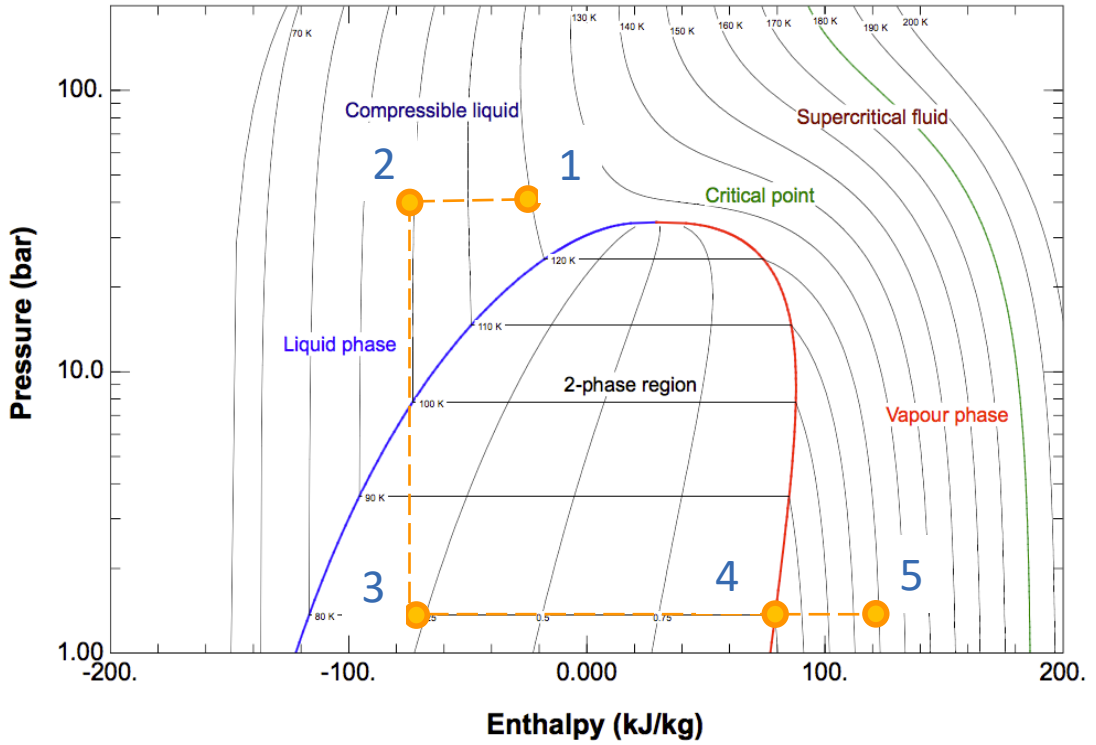
- **Joule-Thomson Cooler**
  - Very good candidate to provide cooling for highly sensitive payloads. But, they often rely on mechanical compressors.
  - Excellent flexibility for its integration in the spacecraft.
- **Sorption Compressor**
  - Attractive solution without moving parts, good integration with J-T cooler.
  - Circulation of the fluid is achieved by cycles of cooling and heating.

80 K Vibration-free cooler

Proposed design/solution



$$\dot{Q} = \dot{m}(h_4 - h_3)$$



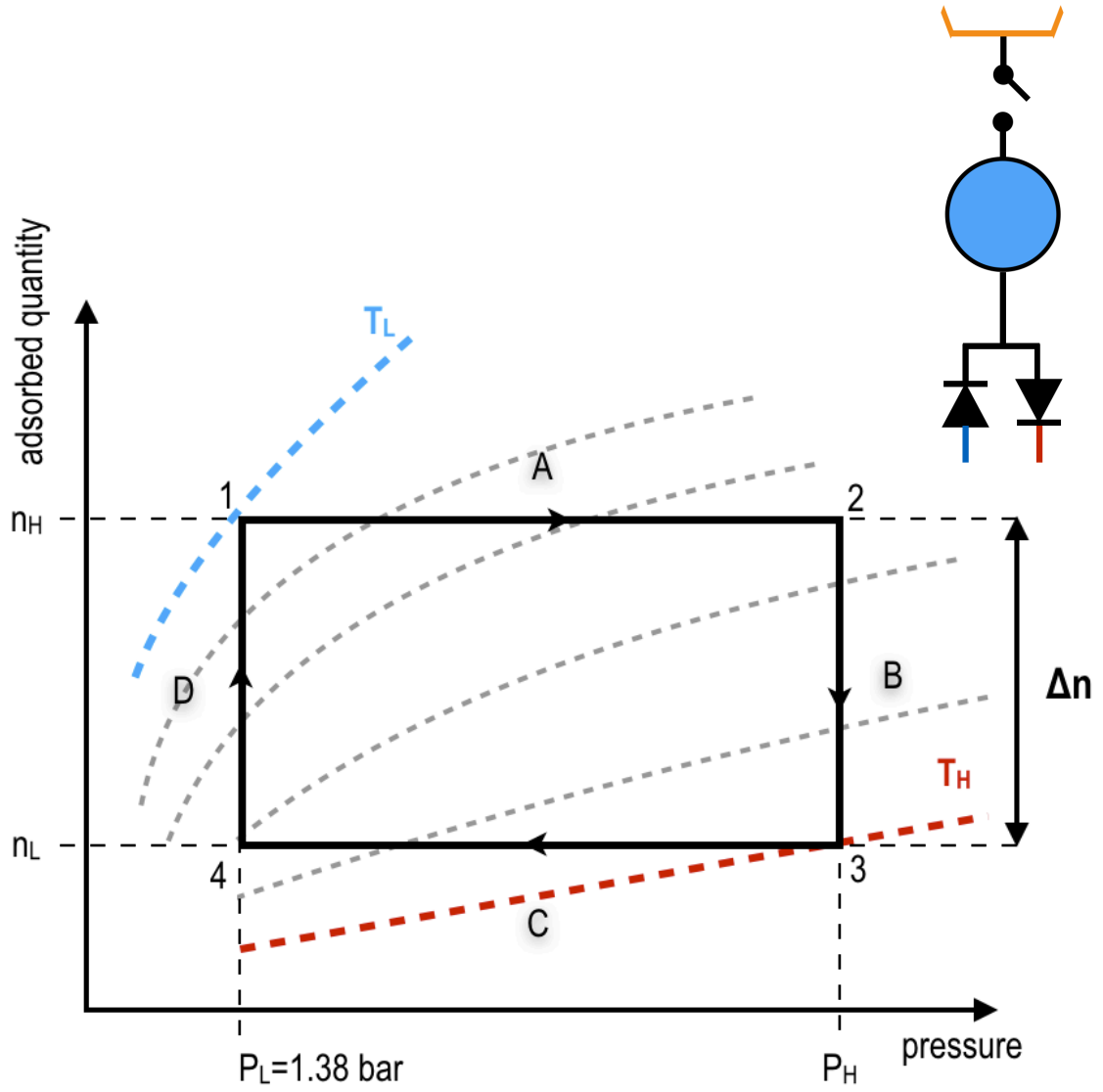
fluid	Cooling Power	Mass flow rate (mg/s)	High Pressure (bar)	Low Pressure (bar)
nitrogen	1.5 W @ 80 K	10.8	40	1.38

Sorption Compressor

Working Principle

The challenge:

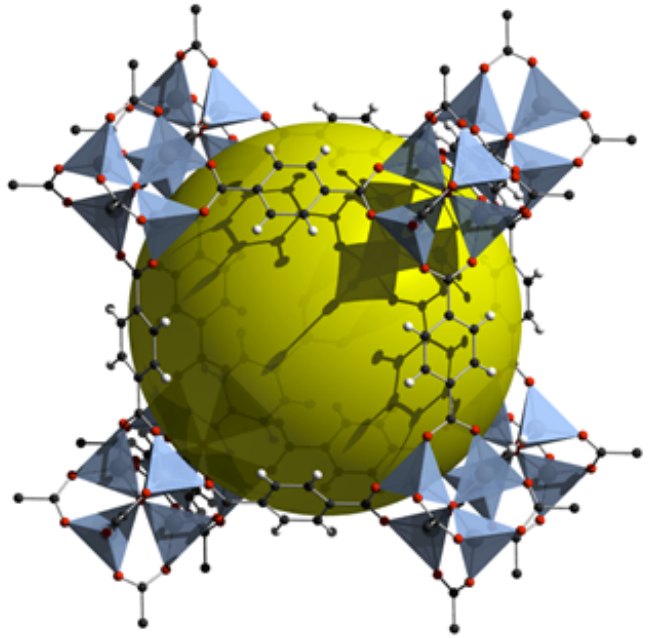
- Available heat rejection capacity is limited (1.5 m^2 radiating at 90 K);
- Adsorption with a minimum temperature T_L of ≈**150 K** and with low heat of adsorption;
- To feed the JT cold stage, a high releasing temperature T_H is expected ≤**500 K**;
- Scarce data on literature for this wide temperature (150-500 K) and pressure range (1-100 bar) are found;
- New materials can be studied for nitrogen adsorption (e.g. metal organic frameworks);



Sorption Compressor

Metal Organic Frameworks

- MOF are promising porous materials due to its high surface areas and pore volumes.
- They can be tailored for specific applications by exploring different combinations of metals and organic ligands.
- Extensive search and simulations of MOF materials using grand canonical Monte Carlo molecular simulations were done.
- Three potential materials were chosen and characterized with nitrogen.



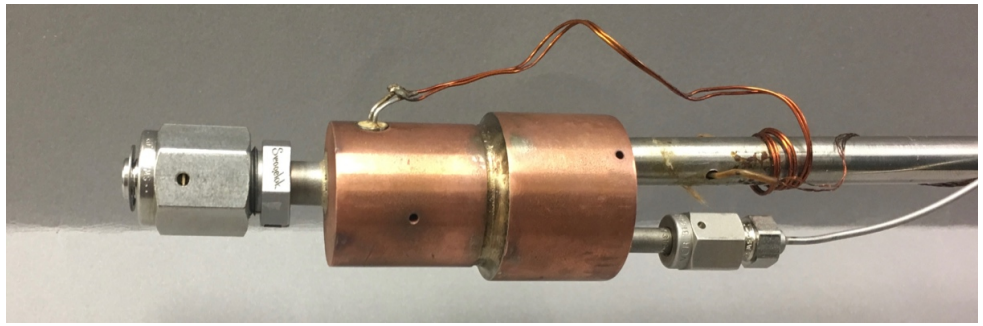
Example of MOF-5 with yellow sphere filling the pore.
Source: https://www.chemistryworld.com/podcasts/mofs-metalorganic-frameworks-/3007204.article

Sorption Compressor

Volumetric setup for MOF characterization

- Home-made volumetric setup to perform adsorption measurements in the temperature range of 77 K to 500 K and 1 bar to 100 bar.
- The results were compared and validated with commercial gravimetric apparatus*.
- At the moment, only HKUST-1 (or CuBTC) was found to be suitable for the nitrogen sorption compressor.

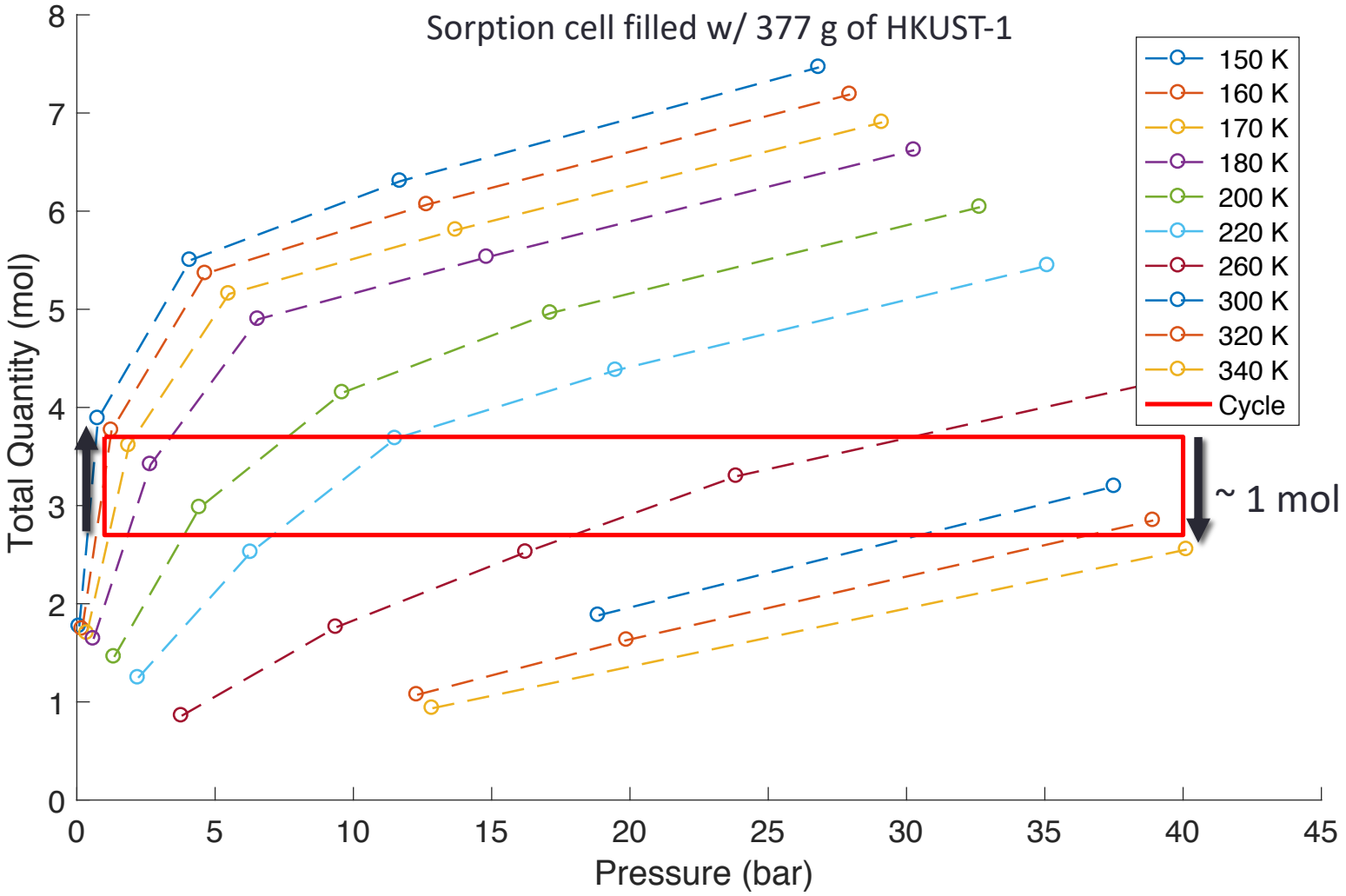
5 cm^3 copper cell filled with HKUST-1

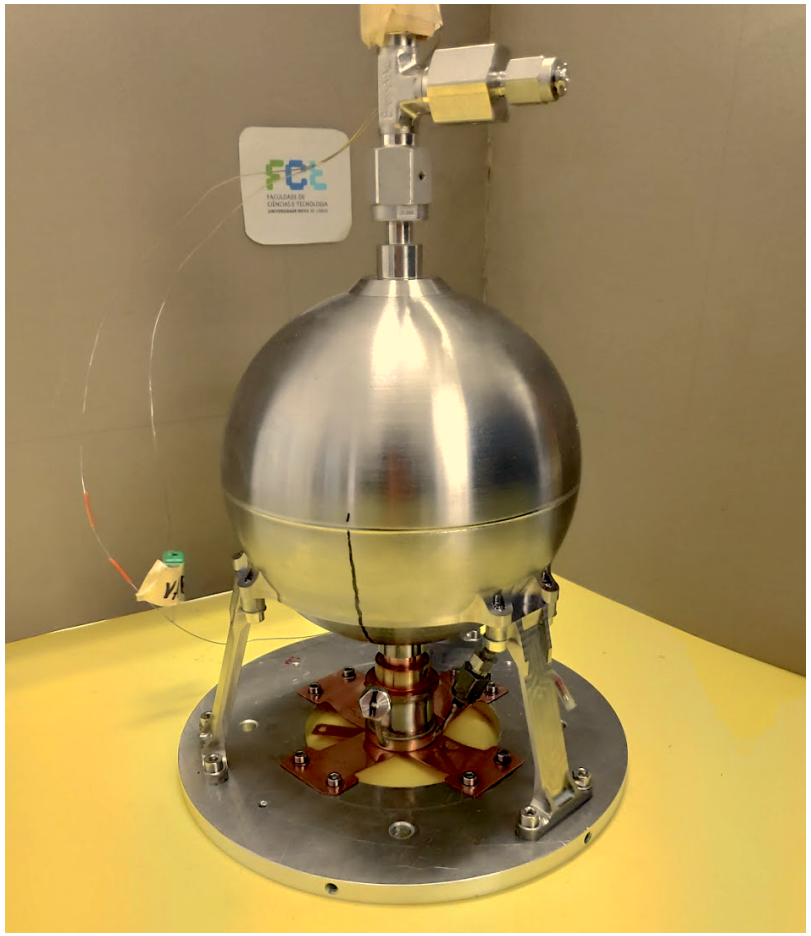


* High-pressure magnetic-suspension balance ISOSORP 2000 (Rubotherm GmbH, Germany)

Sorption Compressor

Adsorption Results

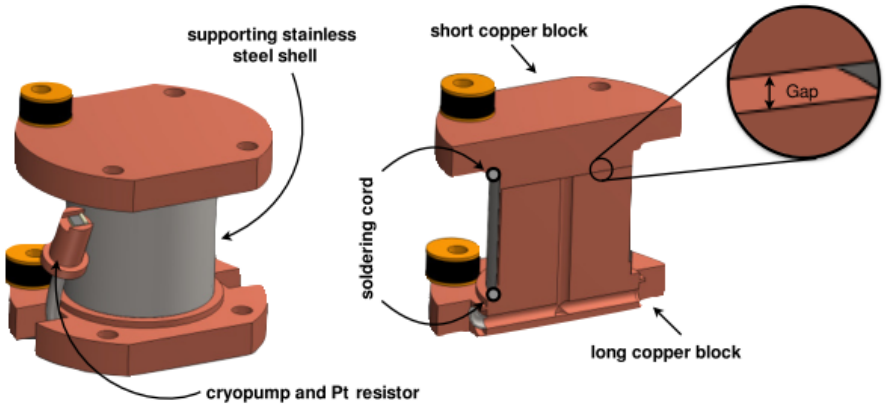




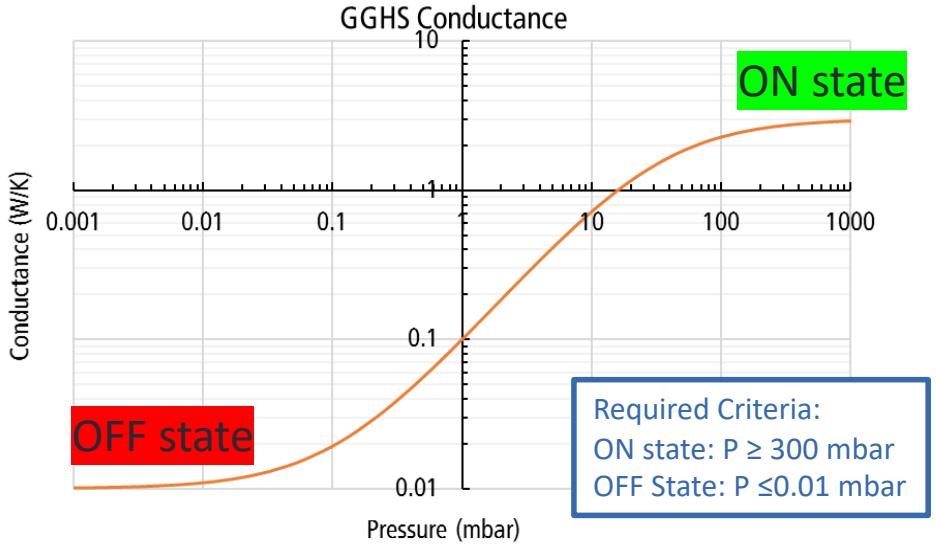
One litre titanium sorption compressor cell, coupled with gas gap heat switch

Sorption Compressor

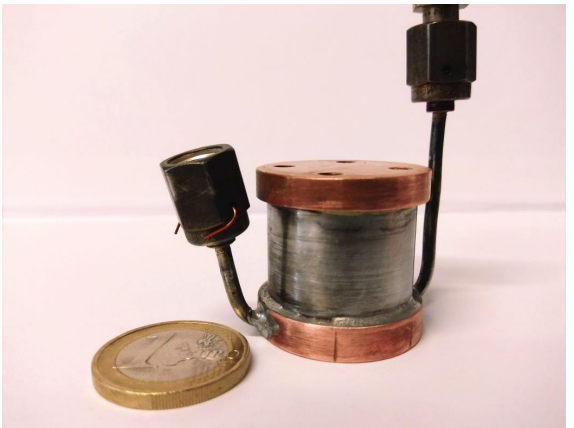
Gas-gap Heat Switch (GGHS)



Franco, J. et al. 2015. "Building a Thinner Gap in a Gas-Gap Heat Switch." *Physics Procedia* 67: 1117–22.



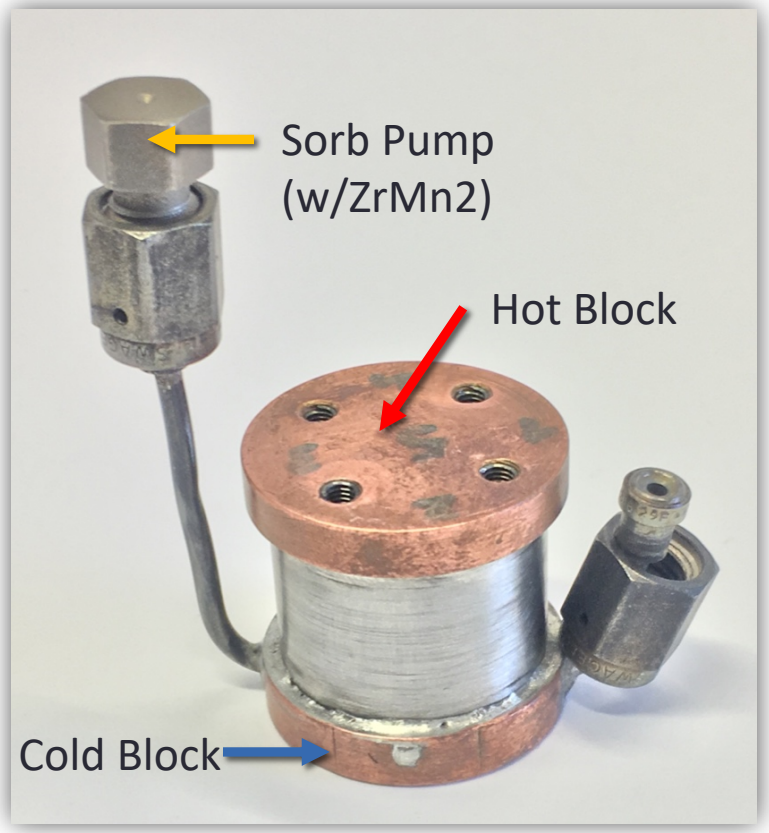
- Cold source: 150-160 K;
- ON state conducting gas: H_2, He
  - **Helium**: Adsorption available only for T < 30 K
  - **H_2**: Chemical absorption available w/ ZrMn2 based metal hydrides
- Expected ON conductance w/ H_2:
  - 3 W/K @ 160 K;
- Expected OFF state:
  - 8 mW/K (150 – 400 K);

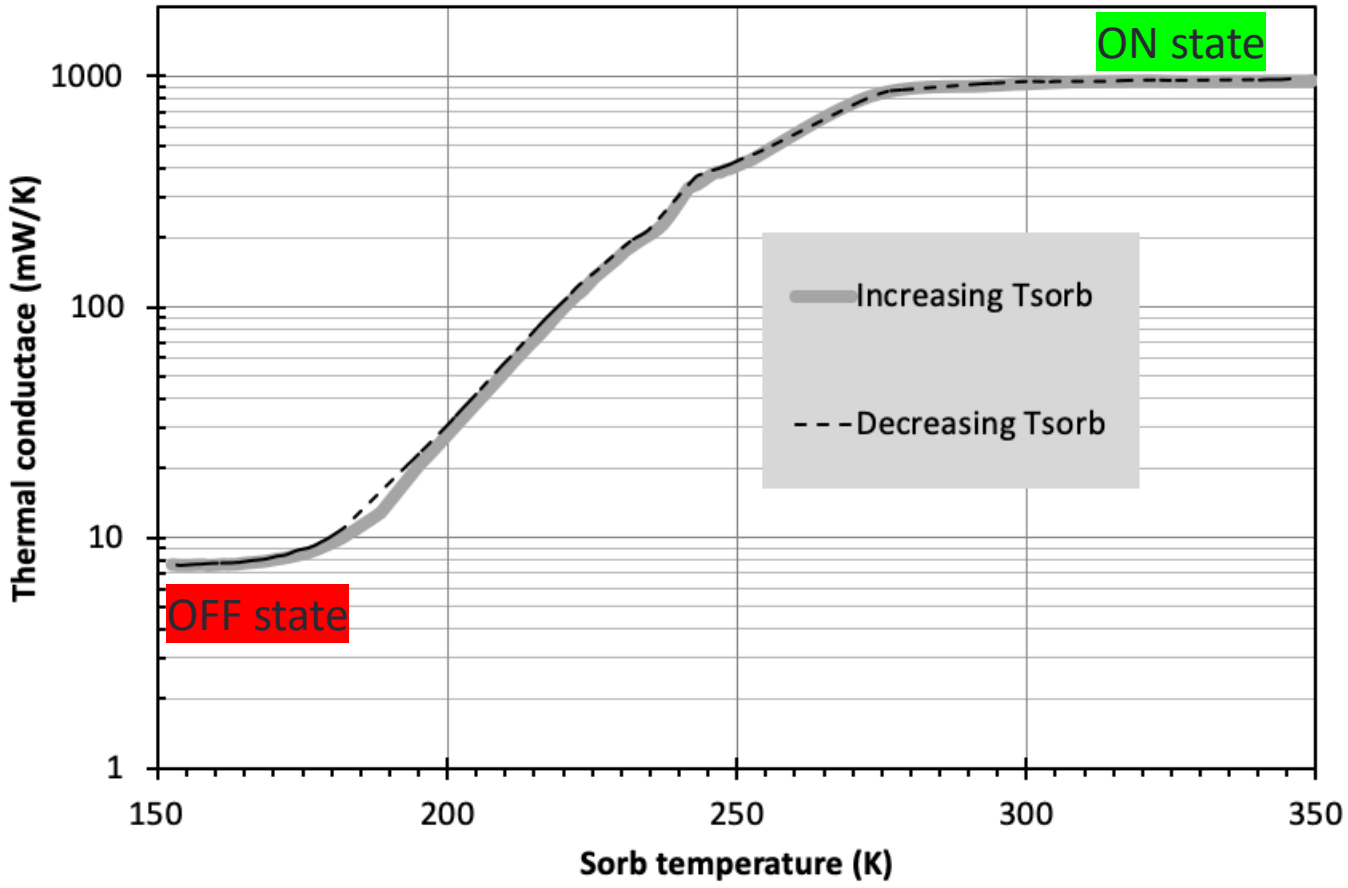


GGHS, 1€ coin for scaling.

Sorption Compressor

Gas-gap Heat Switch (GGHS)





Conclusions

- The 80 K nitrogen vibration-free cooler was designed with a functional operating point: 1.5 W @ 80 K
- The stringent requirements of this project led to the search of new absorbent materials.
  - At the moment, the MOF HKUST-1 was found to be the adequate as sorption compressor.
- A 1 litre sorption cell was filled with 377 g of HKUST-1 and its adsorption capacity was measured.

Conclusions

- A prototype of a GGHS was tested with H_2, a ON/OFF ratio of 125 was measured after being sealed (with H_2+ 2.6 mg $ZrMn_2$).
- Considering the preliminary results, an optimal operating point was found and compatible with ESA's requirements.
- The performance of part of this cooler is under tests.

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