UNIVERSITY OF TWENTE.

Test results of sorption-based helium-3 pump for a closed-cycle dilution refrigerator

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(2) (3) (4) (5)

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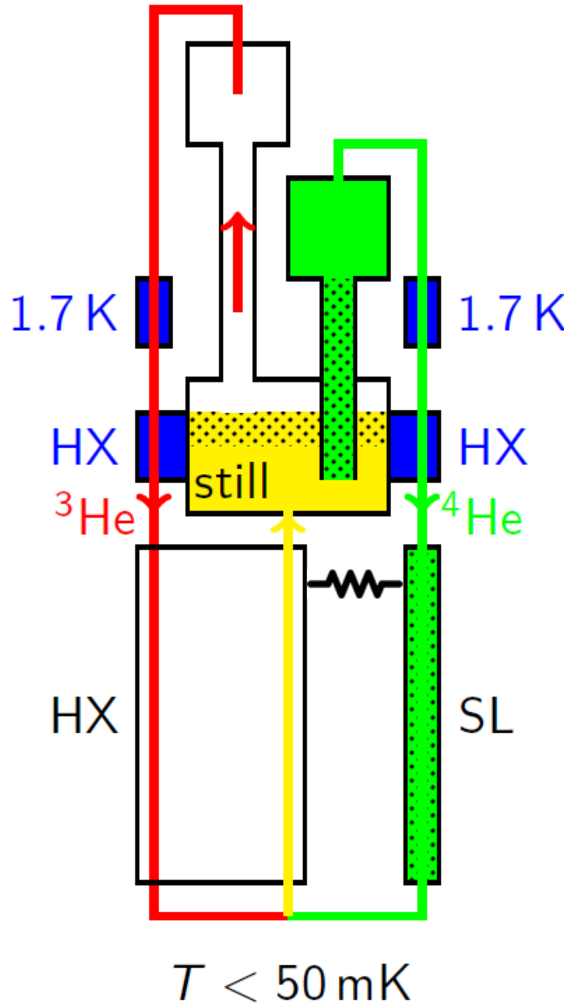
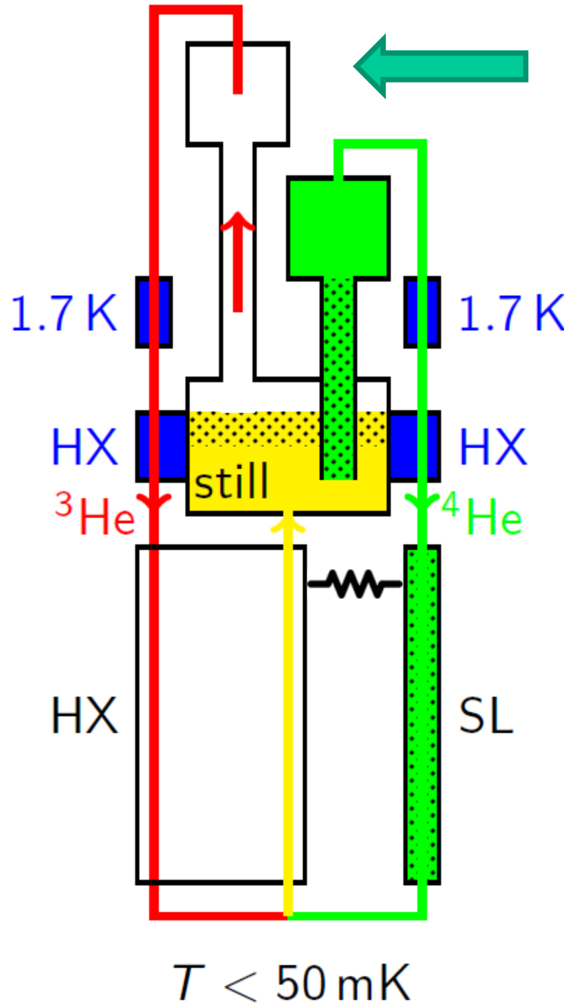


Closed-Cycle Dilution Refrigerator
Presented by Gerard Vermeulen



“missing link”: He-3 circulator pump

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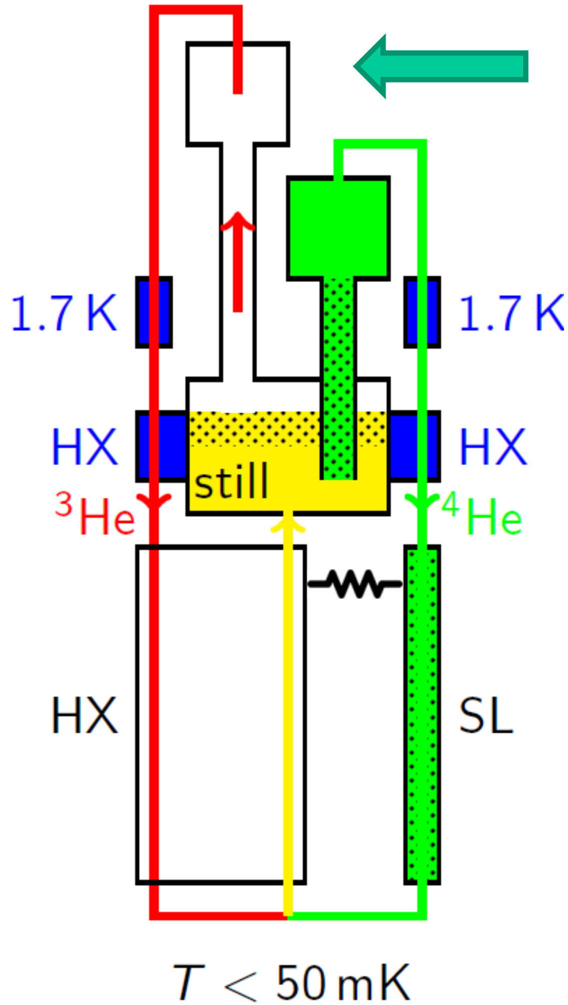

"missing link": He-3 circulator pump

He-3 pump requirements	
Circulation rate:	10 – 30 µmol/s
	(20 µmol/s assumed in study)
Suction pressure:	5 mbar
Outlet pressure:	200 mbar
Lifetime:	5 – 10 years
Mass (incl. electronics) :	< 3 kg
Heat sink available:	100 mW at 15 K
	+ 2 – 5 mW at 1.7 K
Max. pressure at 300 K:	20 bar
Vibration levels:	20 g
1st resonance freq.:	> 100 Hz
Input power:	< 30 W

Closed-Cycle Dilution Refrigerator
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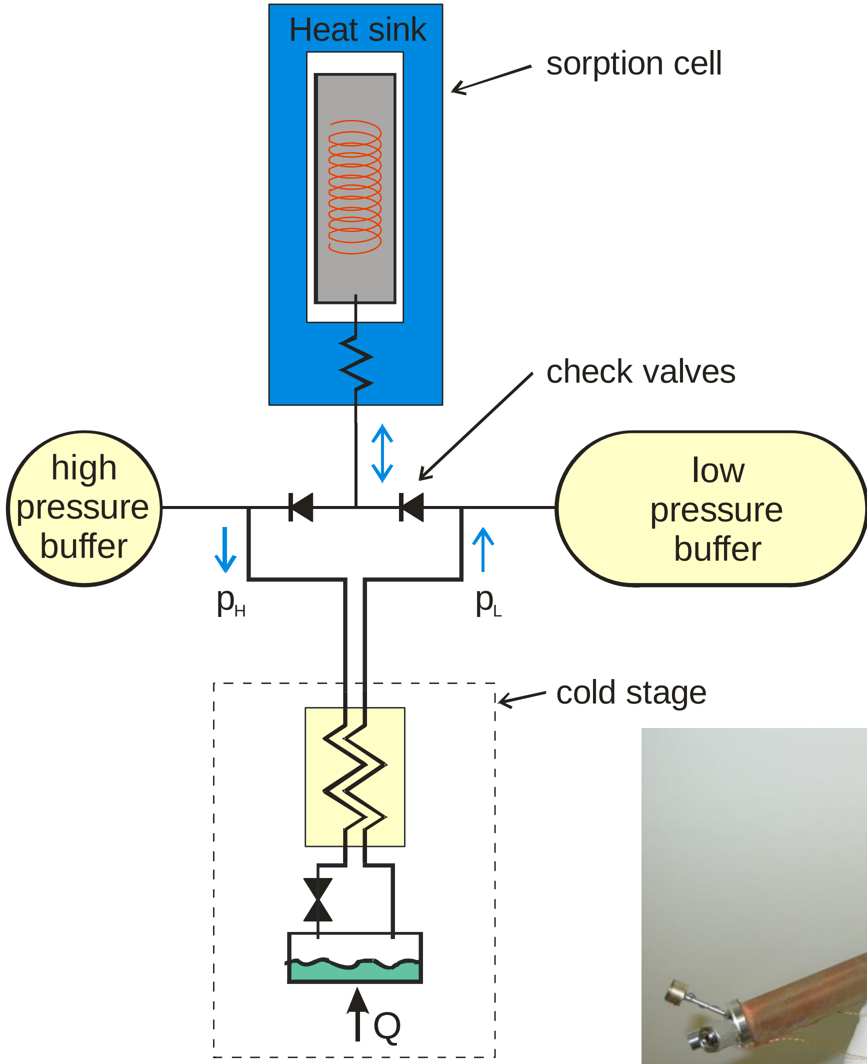
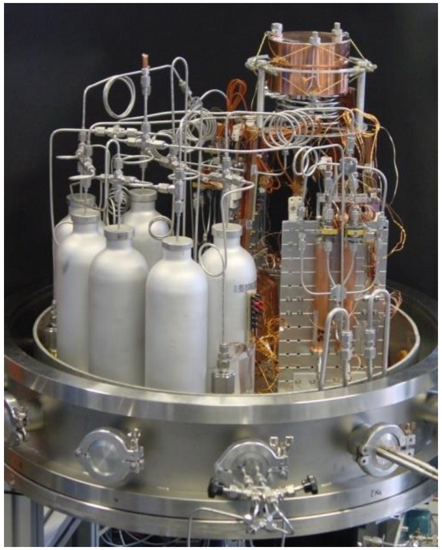
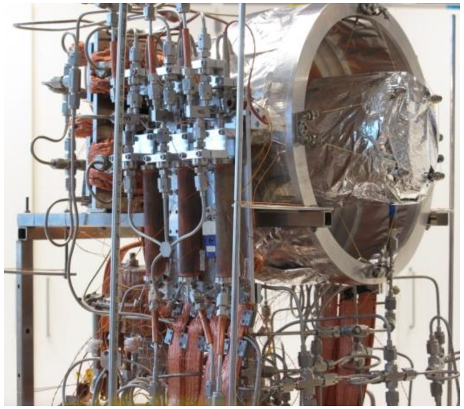
Sorption cooler heritage at University of Twente



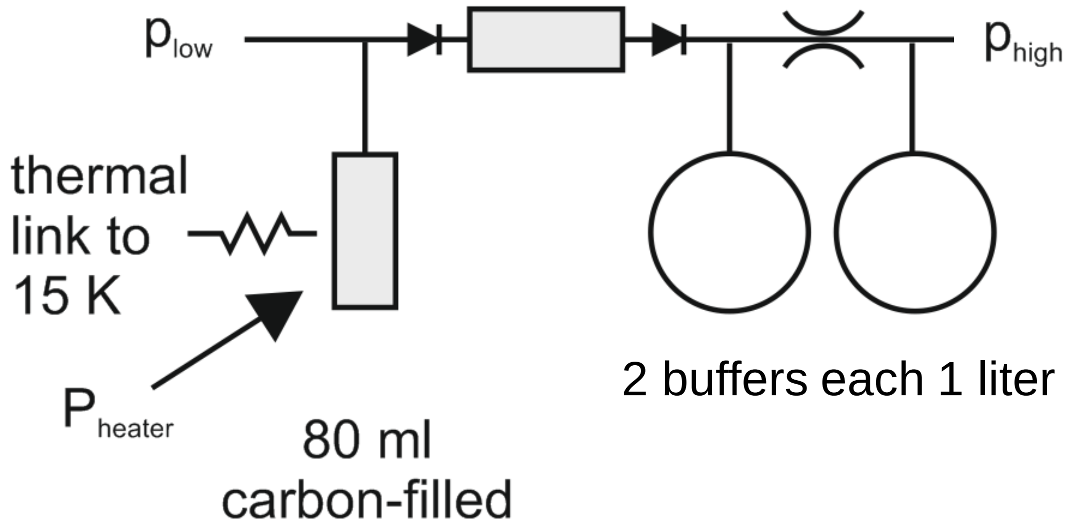


4.5 K helium cooler (CEC 2007)

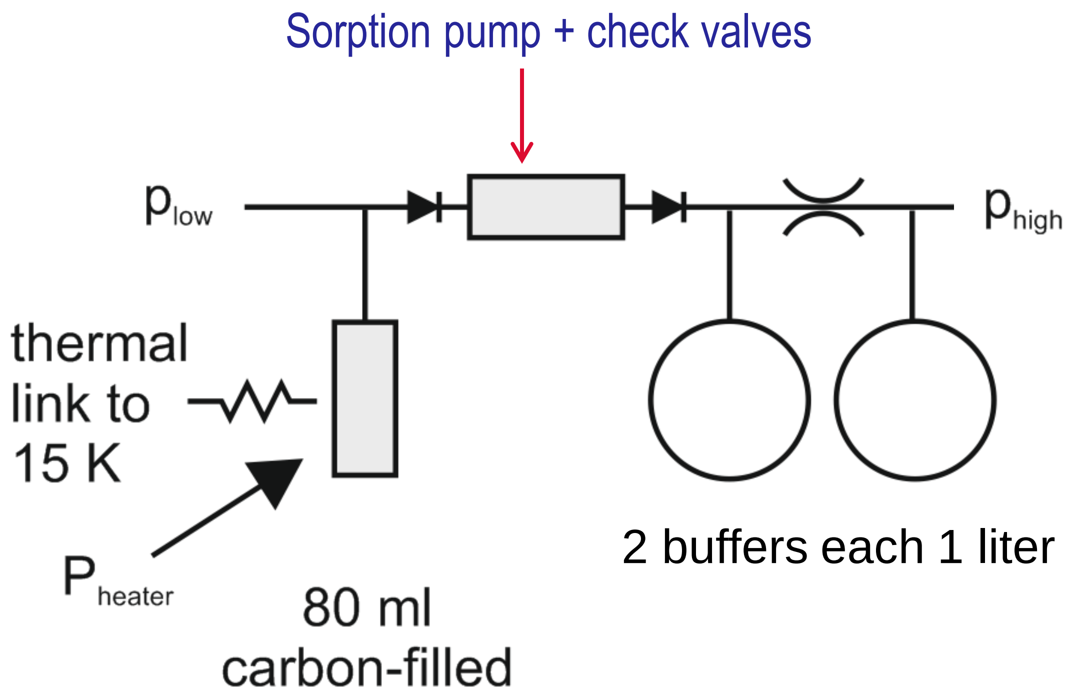


14.5 K hydrogen cooler (CEC 2013)

Sorption-based He3 pump conceptual design

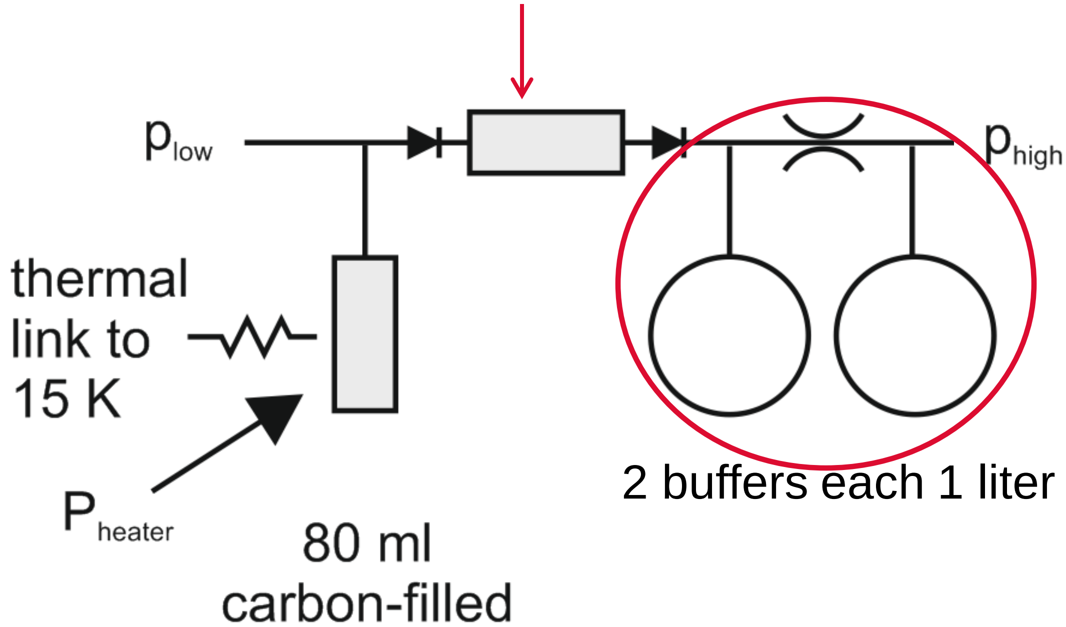


Sorption-based He3 pump conceptual design



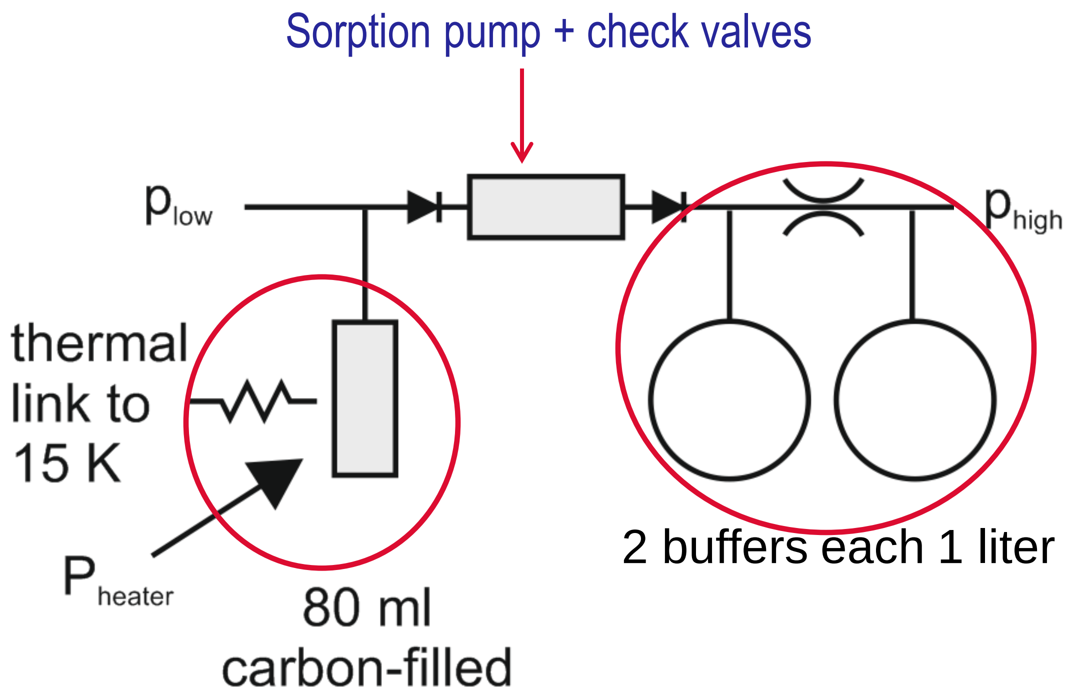
Sorption-based He3 pump conceptual design

Sorption pump + check valves



Buffers for storing gas at 300K;
Two buffers + restriction to dampen peak in out flow

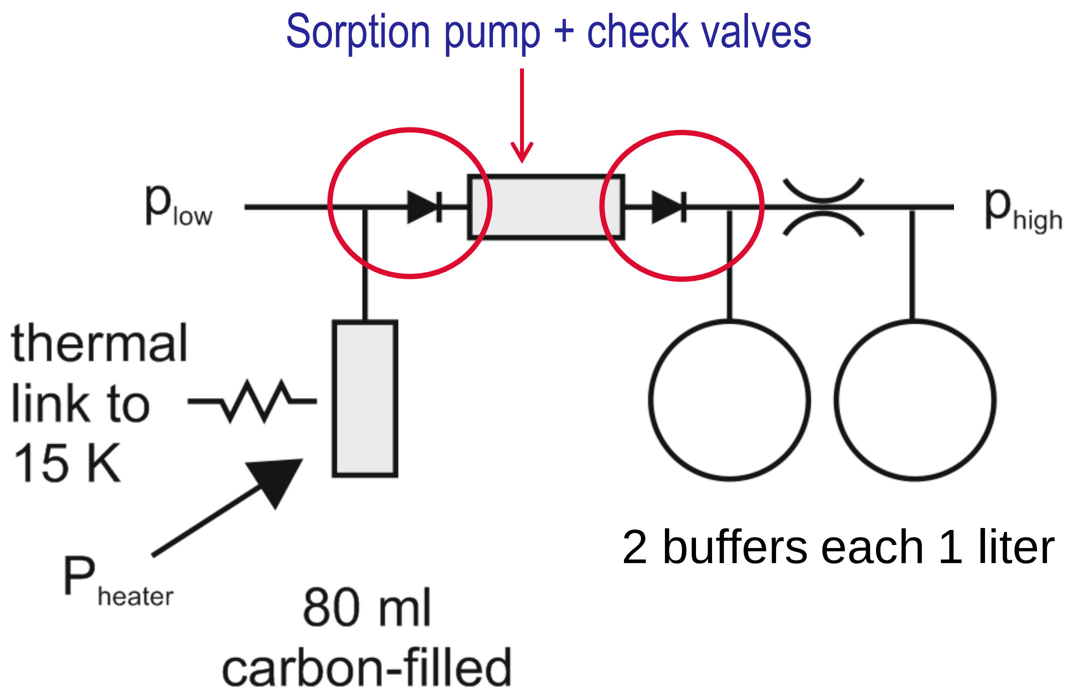
Sorption-based He3 pump conceptual design



Buffers for storing gas at 300K;
Two buffers + restriction to dampen peak in out flow

T-controled low-pressure buffer for stabilizing flow (without T-control, flow varies ca.10%)

Check valves: requirements



Check valves:

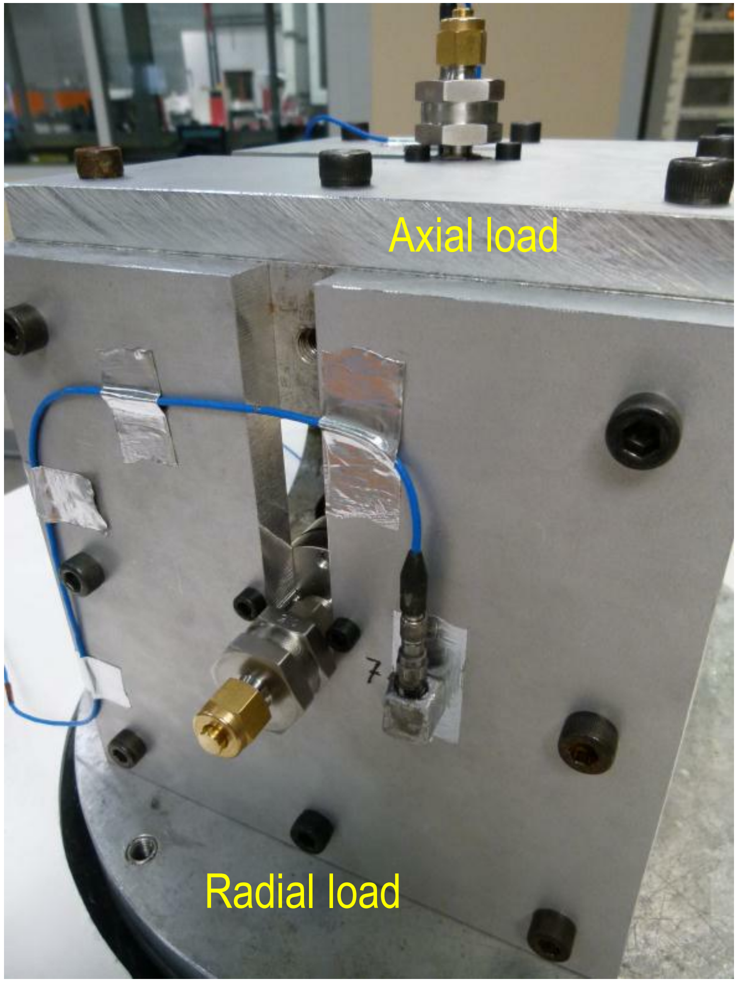
Forward pressure drop: < 0.5 mbar (in 5 mbar suction valve)

Reverse leakage flow: < 1% of forward flow

Check valves: vibration tests

Sine vibration test

Frequency bandwidth: .... from 5 to 100 Hz
Amplitude: .... 24 mm (peak to peak) from 5 to 20.5 Hz
20 g from 20.5 to 60 Hz
8 g from 60 to 100 Hz
Sweep rate: .... 2 oct/min
Number of sweep:.................... 1
Number of axes:....................... X on specimen n°2
Y on specimen n°7

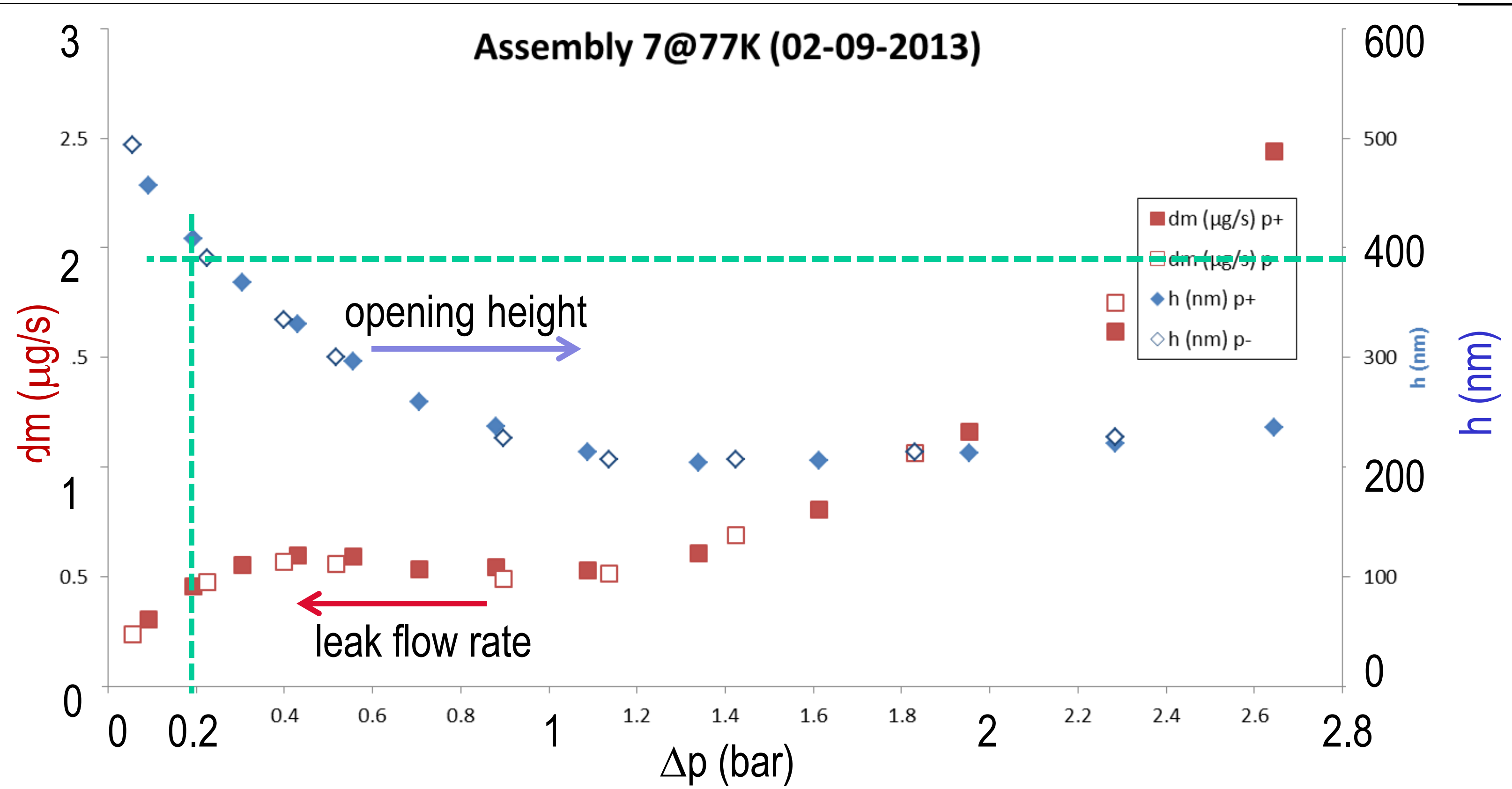


Robust Random Vibration Test

Frequency bandwidth: .... from 20 to 2000 Hz
Amplitudes: .... see table below
Duration: .... 2 minutes 30
Number of axes:....................... X on specimen n°2
Y on specimen n°7

Frequency (Hz)	Amplitude (g²/Hz)
20	0.016
80	0.26
500	0.26
2000	0.065
Overall level	**17 g_{rms}**

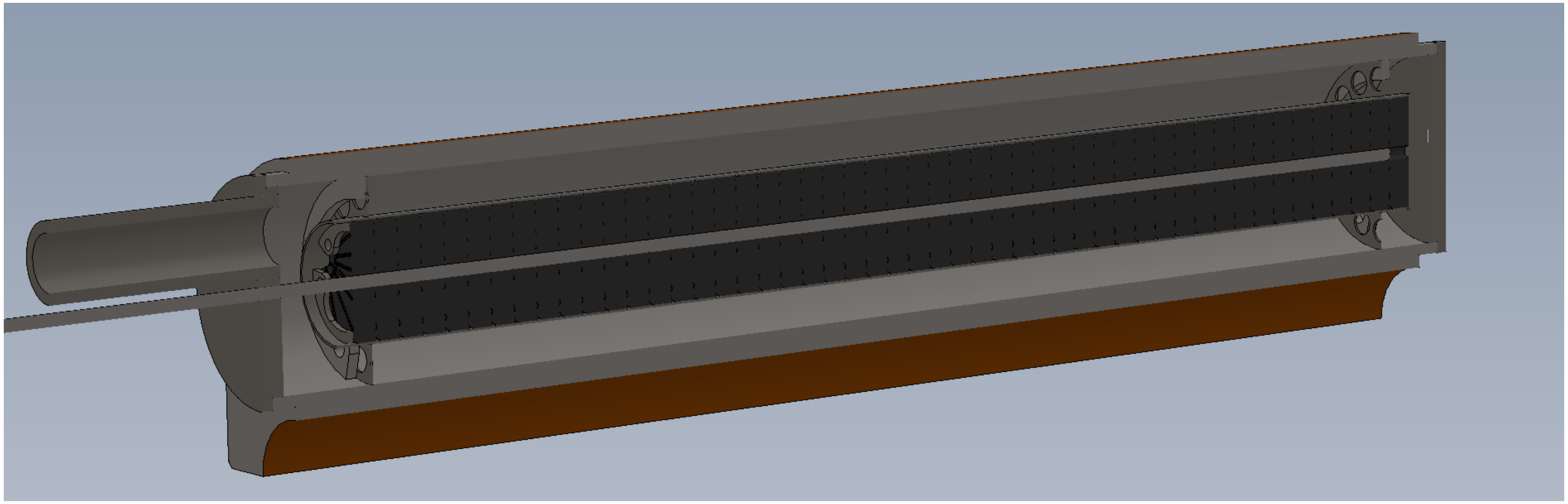
Check valves: leak test at 77 K before (open symbols) and after shaking (closed)

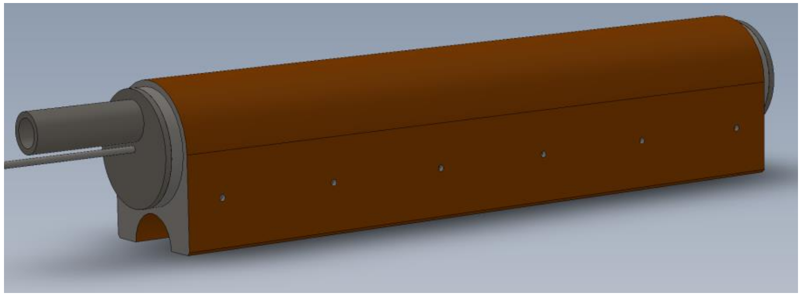


Seat #	Flap #	gapheight (nm) min	nom	max	flowrate @ 15K (ug/s) min	nom	max	% forw flow (60 ug/s) @ 15K min	nom	max
Assembly 7 @ 77K	7	204	**400**	494	0.1	**0.6**	1.1	0.2%	**1.0%**	1.8%
Assembly 9 @ 77K	8	302	**415**	445	0.3	**0.7**	0.8	0.5%	**1.1%**	1.4%
Assembly 4 @ 77K	3	293	**410**	656	0.3	**0.7**	2.5	0.4%	**1.1%**	4.1%

Compressor design and realization

Carbon cell length 10 cm. Carbon pill diameter 9 mm, gap 2 mm (no gas-gap heat switch!)
Pressure drop in cell and tubing (< 0.1 mbar); spacing between carbon pills





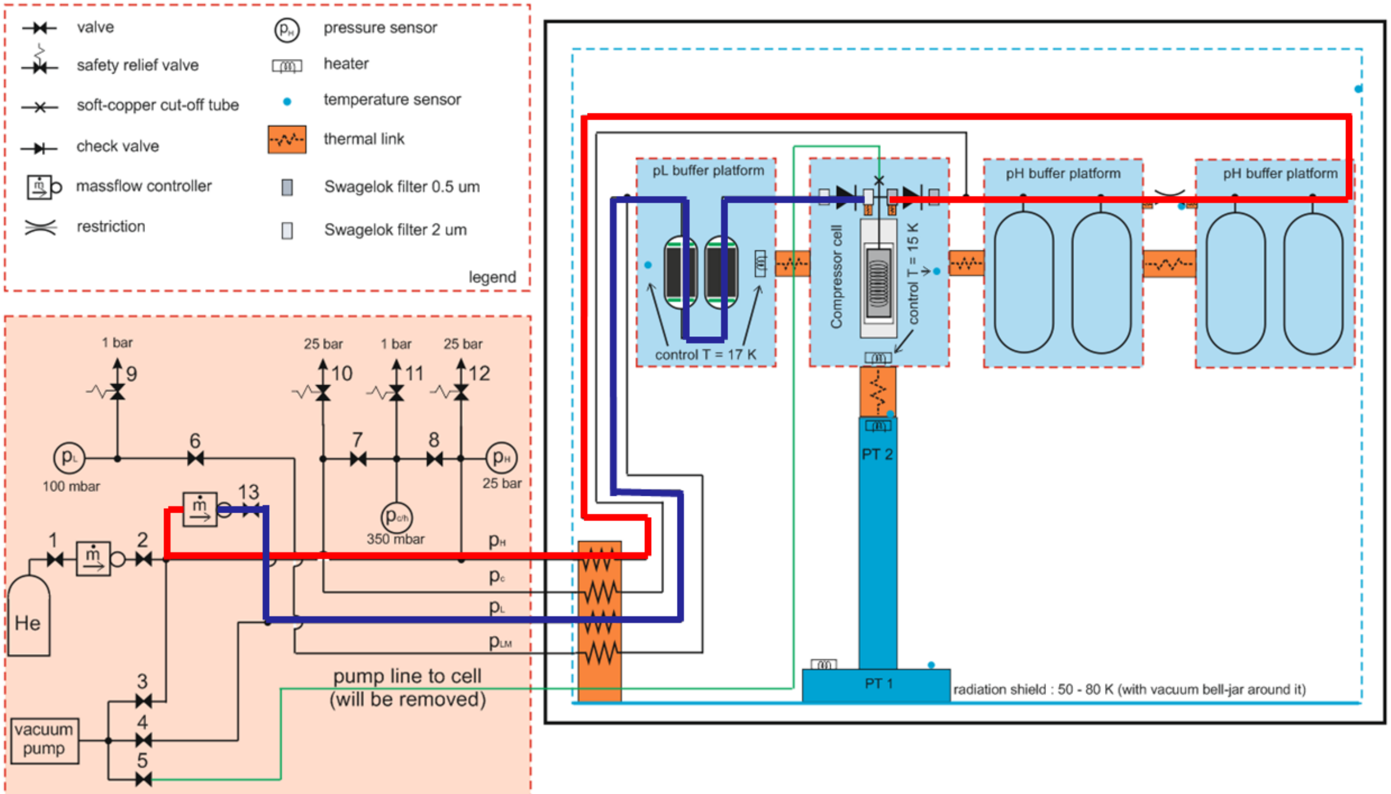
Measurement setup

$$\dot{m} = c\, p_{high}$$

→ c is controlled so p_{high}=200mBar on average

Each cycle has a specific c

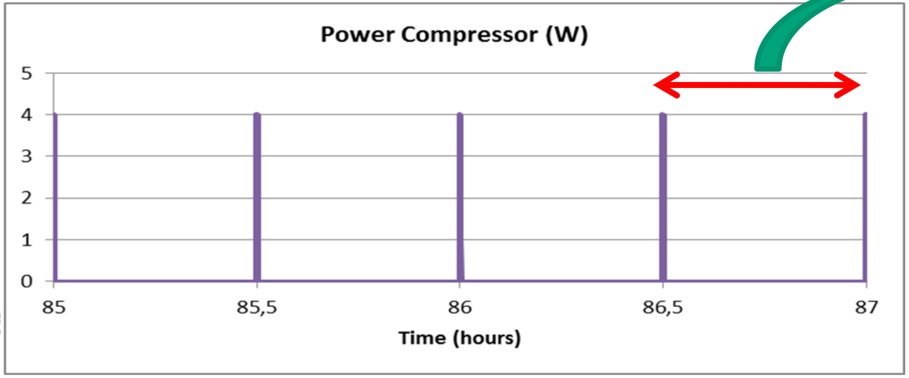
test experiments with He4 (sorption characteristics similar to He3)

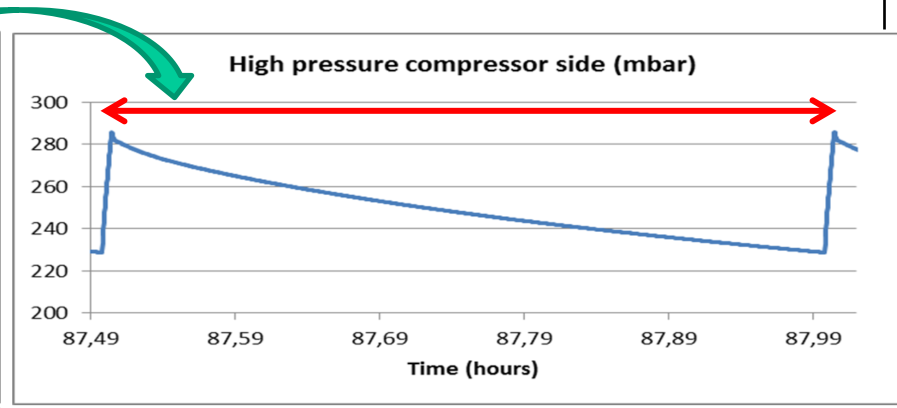


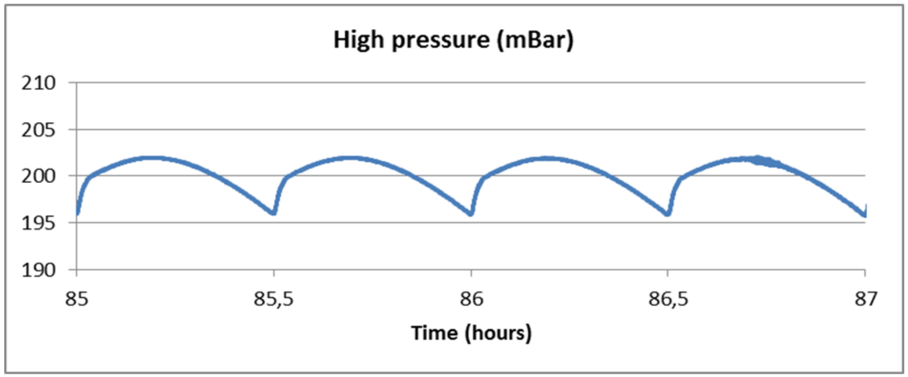
- Low pressure stabilization at 5 mbar (optional)
- Only output is mass flow
- FOM for performance is mass flow/input powers

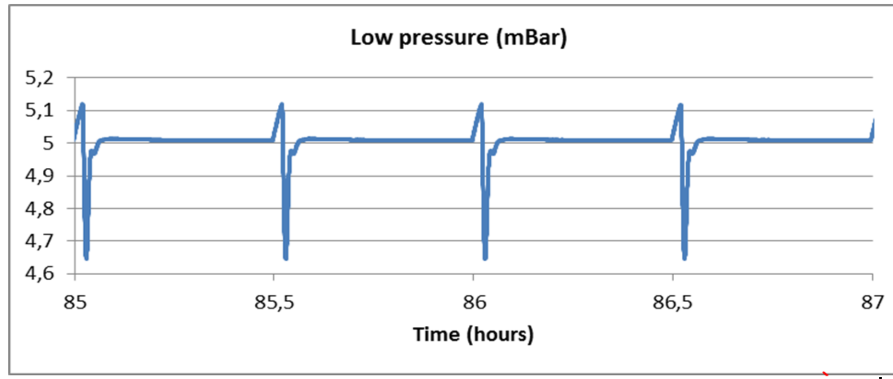
Test results of sorption pump

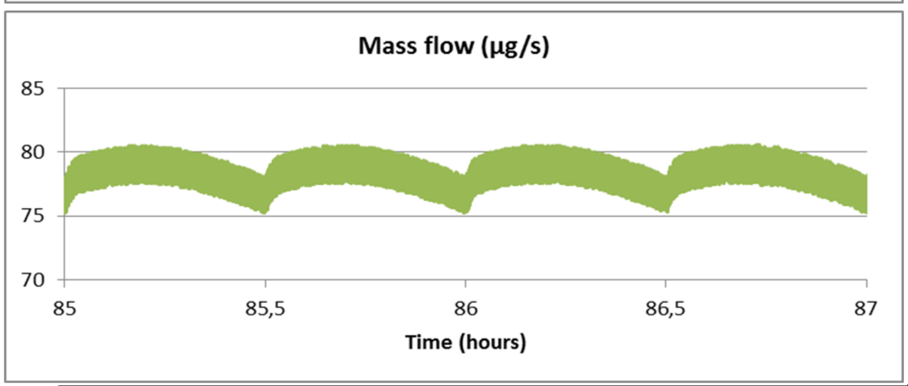
Nominal setting with control of p_{low}







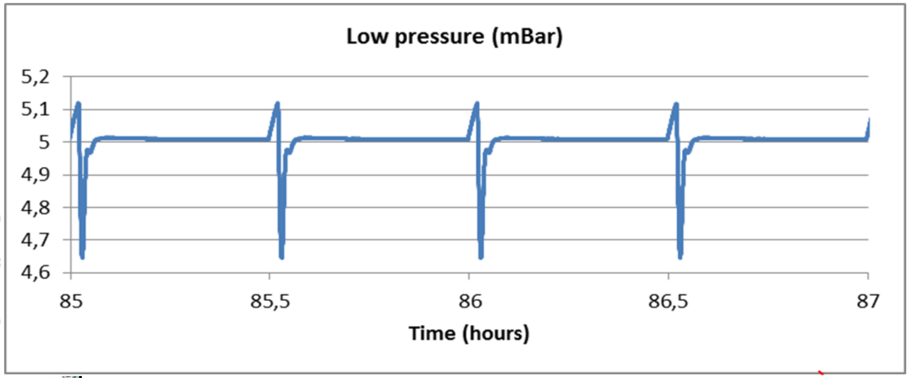


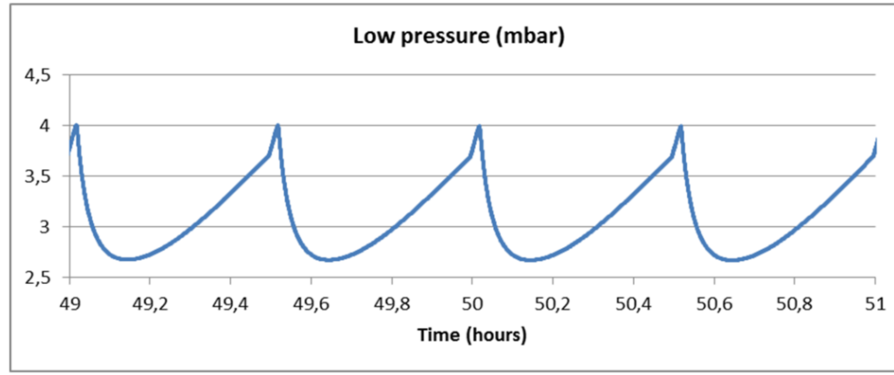


- Peak heating power = 4.0W
- Heating time = 28s
- Cycle time = 1800s
- p_{low} = 5 mbar (controlled through temperature of low pressure buffer platform)
- p_{high}= 200 mbar (controlled by mass flow)

Test results of sorption pump

Yes or No…. p_{low} control ??





With control:

P_{low} varies 0.5 mbar

Power input doubles (60 to 120 mW)

Without control:

P_{low} varies 1,3 mbar

Power input only for pump (60 mW)

	t_cycle (s)	t_heat (s)	Pwr_comp (W)	p_low (mBar)	Avg mass flow (µg/s)	p_high 1 (mbar)	Avg Pwr p_low (W)	Avg Pwr total (W)	FOM tot ((µg/s)/W)	FOM comp((µg/s)/W)	Ratio FOM tot (%)	Ratio FOM comp(%)
1. Nominal settings 1: reference	1800	28	4	5	78,4	229-286	0,059	0,121	647	1260	0%	0%
2. Nominal, no p_low control	1800	28	4	2,7-4	72,6	238-292	0	0,062	1167	1167	+80%	-7%

What p_{low} variation is acceptable?

Test results of sorption pump Verification matrix

ID	Requirement	Short description	Measured Value	Achieved
F1	Flow rate: 10-30 µmol/s	Measured by a Bronkhorst flow controller at room temperature using He-4.	19.6 µmol/s	✔
F2	Low pressure 5-10 mbar	Measured at room temperature by a MKS pressure transduces with a range of 100 mbar. Can be controlled to stable pressure by controlling the buffer temperature, accepting extra input power	Control at 5 mbar gives fluctuations of 4.6-5.1 mbar	✔
F3	High pressure: 200 mbar	Measured at room temperature by a UNIK 5000 pressure sensor with a range of 350 mbar and improved accuracy	200 mbar (controlled)	✔
F4	Flow stability +/- 10 %	Mass flow sensor at room temperature	75-81 µg/s, is within 10%	✔
F5	External leak rate : < 10^{-6} mbarL/s	Helium leak test	Tested and achieved	✔
F6	Outgassing: low	Design requirement		✔
S1	Life time: 5-10 years	No experiment, analysis only		✔
S2	Mass: < 3 kg	Mass measured on component level	5.9 kg mostly buffers	NA
T3a	Heat sink temperature: 15 K	Cryogenic temperature sensor in feedback loop, also higher temperatures possible.	15 K controlled	✔
T3b	Heat rejection at 15K: ≤ 100 mW	Heater power to control low pressure buffer platform and the heater power to the compressor will be measured and added.	121 mW	close
T5	Non-operating temperature: 223-323K	Design requirement only		✔
M1	Pressure at 300 K: ≤ 20 bar	Filling pressure will be around 12 bar and filled mass will be measured	9.0 bar	✔
M2	Vibration levels: 20g (Ariane 5 spectrum)	Design requirement, no measurements		✔
M4	Minimum pressure : 0 bar (abs)	Design requirement, intrinsically tested		✔
M5	First resonance frequency : > 100 Hz	Design requirement, no measurements		✔

Conclusions and recommendations

Conclusions

- Pump delivers 19.6 μmol/s between 5 and 200 mbar
- Requirement on low-pressure stabilization is critically important
- Sensitivity analyses shows that only a higher low pressure increases pump performance (higher filling pressure)

Future activities

- Interfacing with dilution refrigerator (requirement on p_{low})
- Run with He-3
- Low-pressure buffer heater in the carbon (more direct control)
- Reduce peak heat load to heat-sink platform
- Analyze attainable reduction in size and mass