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Dynamic Regulation of Sub-Atmospheric Pressure for Constant and Cyclic Gas Loads During Testing of Spacesuit Components

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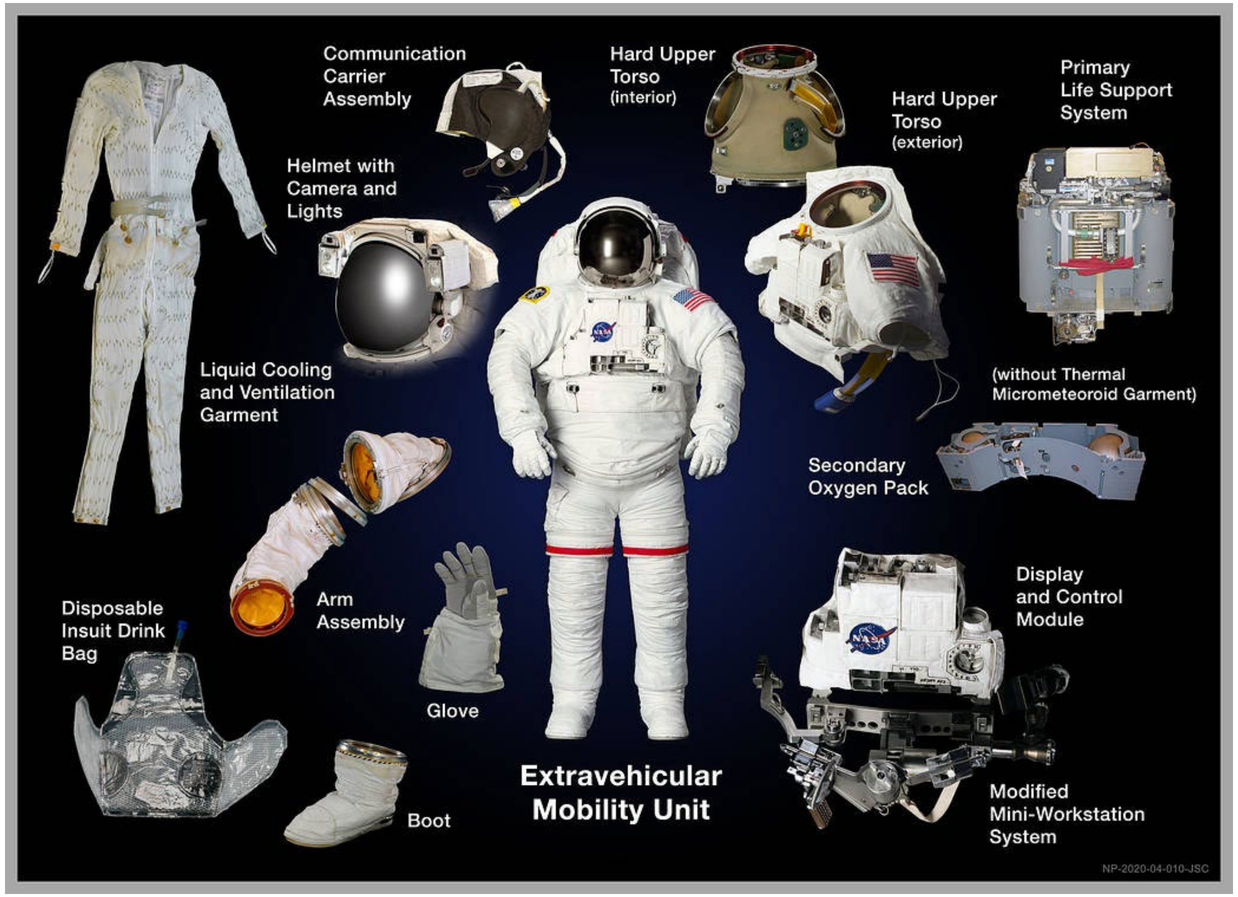
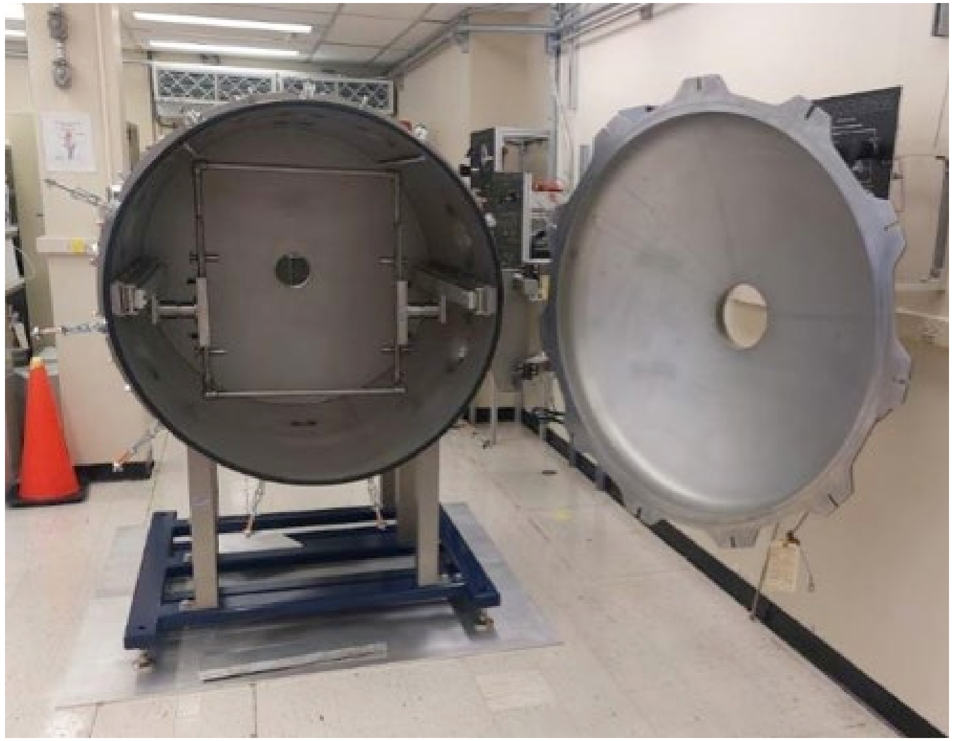
Portable Life Support System

NASA xEMU Spacesuit



Credit NASA: https://www.nasa.gov/image-article/extravehicular-mobility-unit-emu/

NASA PLSS Test Stand (PTS) Vacuum Chamber



Ogilvie, R., A. Moore, and A. Romero, “Space Suit Portable Life Support System Test Stand Overview,” in 54th International Conference on Environmental Systems, ICES-2025-219

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Sorbent Locations within the Exploration Portable Life Support System (xPLSS)

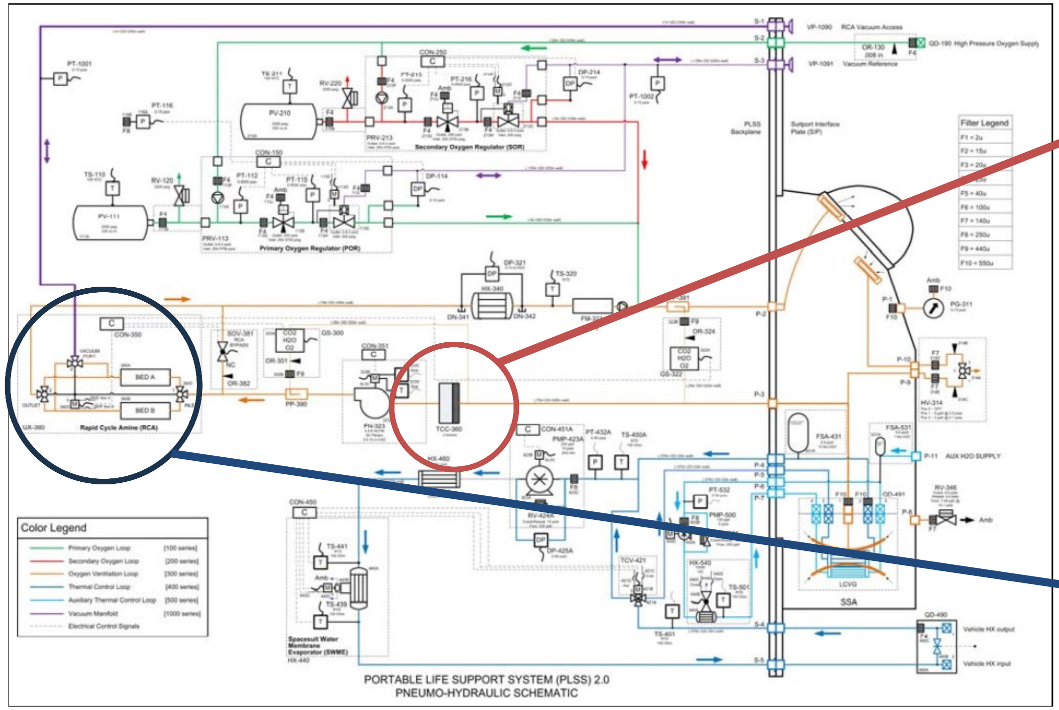

Figure 1. PLSS 2.0 Pneumo-Hydraulic Schematic

Watts, C. and M. Vogel, Space Suit Portable Life Support System (PLSS) 2.0 Human-in-the-Loop (HITL) Testing, ICES-2016-87

The Trace Contaminant Control Unit

- Current non-regenerable sorbent is Ammonasorb II
- We have tested Ammonasorb II and other non-regenerable sorbents
- We are testing XploSafe's Airosorb, which is a regenerable sorbent

The Rapid Cycle Amine (Swing-Bed):

- Current state-of-the-art sorbent is SA9T
- We are testing Xplo-SA9T, MMPA-Sorbent, and CarboXpel

Rigorous testing is required on all new sorbents/systems at realistic conditions

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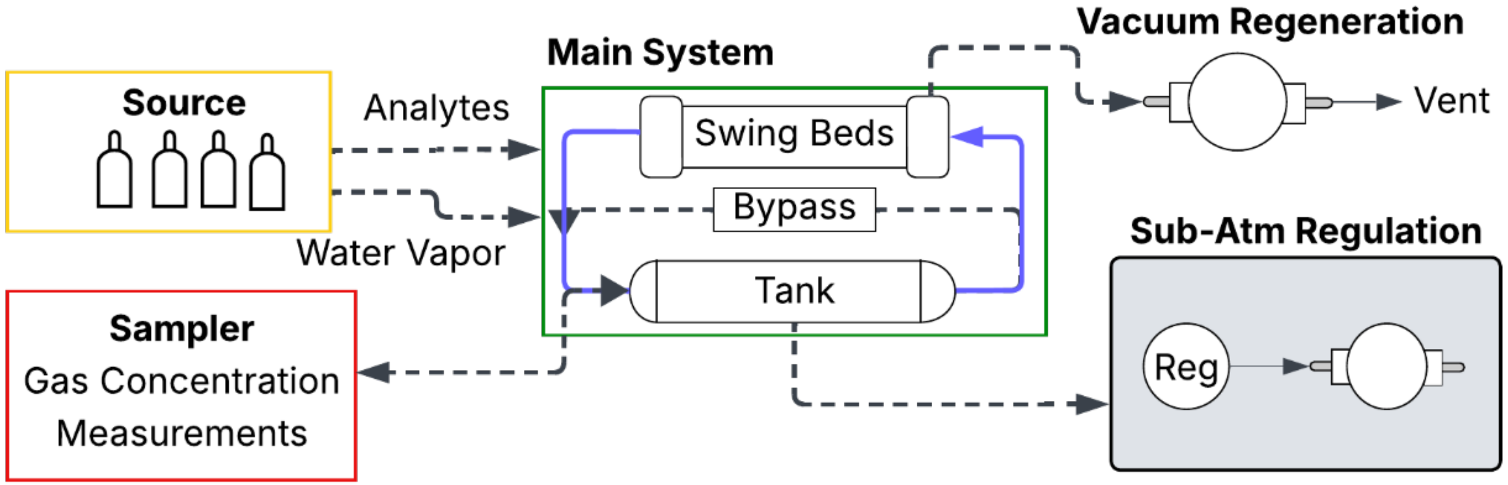
Simplified Illustration of the XploSafe TCC and RCA Test Rigs



Lunar EVA: Pressure of 29.6 kPa (4.3 psia), Gas flow rate of 170 LPM (6 ACFM), xPLSS volume of 56 L (~2 ft^3)

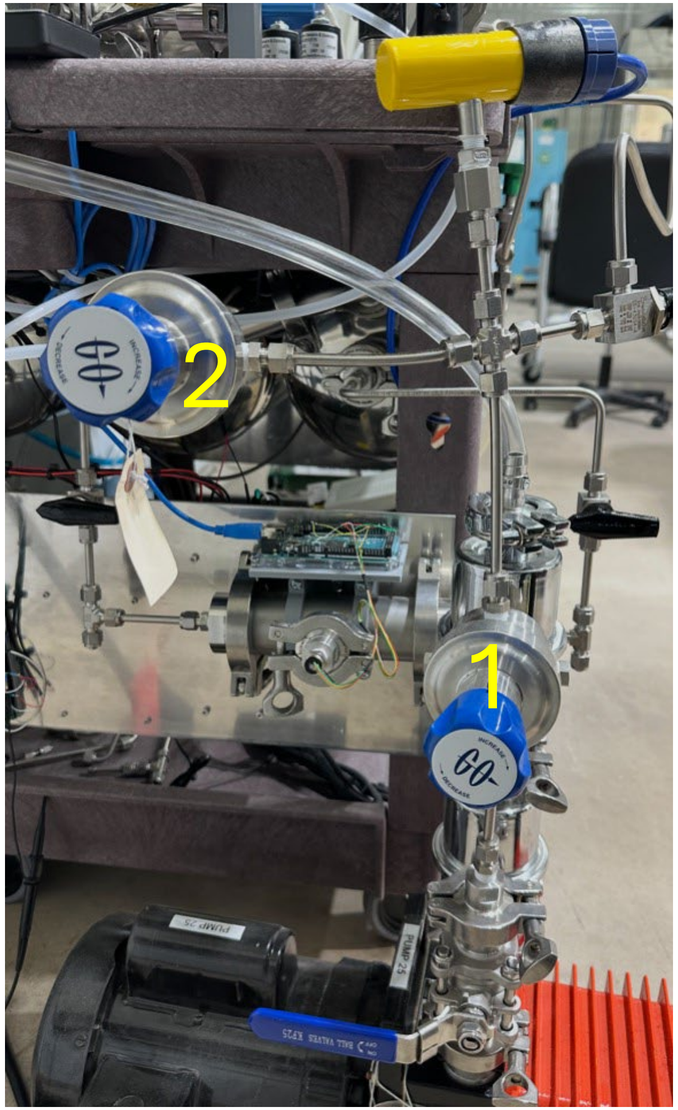
Testing Non-Regenerative Sorbents

- Needs recirculation (contaminant accumulation, reduced gas consumption)
- Gas loss only to balance contaminant injection
- Runs last 150+ hours

Testing Regenerative Sorbents

- Needs recirculation (contaminant accumulation, reduced gas consumption)
- Larger gas exchange (~1 L per-swing for XploSafe’s Test Beds)
- Shorter runs (~8 hours, traditional maximum EVA duration)

Sub-Atmospheric Pressure Regulation: Overview



Regulator 1

- Back-pressure regulator between the Sub-Atmospheric System and the vacuum pump.

Regulator 2

- Pressure regulator between the Sub-Atmospheric System and the Zero-Grade Air source.

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Single-Stage Regulator

Spring

Diaphragm

Valve

Normal Regulator

- Bottom of the diaphragm is the Outlet
- Valve closes when pressure increases to setpoint

Back-Pressure Regulator (Illustrated)

- Bottom of the diaphragm is the Inlet
- Valve begins to open when pressure exceeds the setpoint

Considerations

- Regulates pressure differences
- Response limited to a range around the setpoint
- Spring tension
- Diaphragm size
- Debris intrusion

GO Regulator (https://goreg.com/product/sbpr)

Sub-Atmospheric Mechanical Pressure Regulation: Detailed Description

If the pressure increases above the setpoint:

- Regulator 1 opens, and the vacuum pump restores the pressure

If the apparatus falls below the desired setpoint:

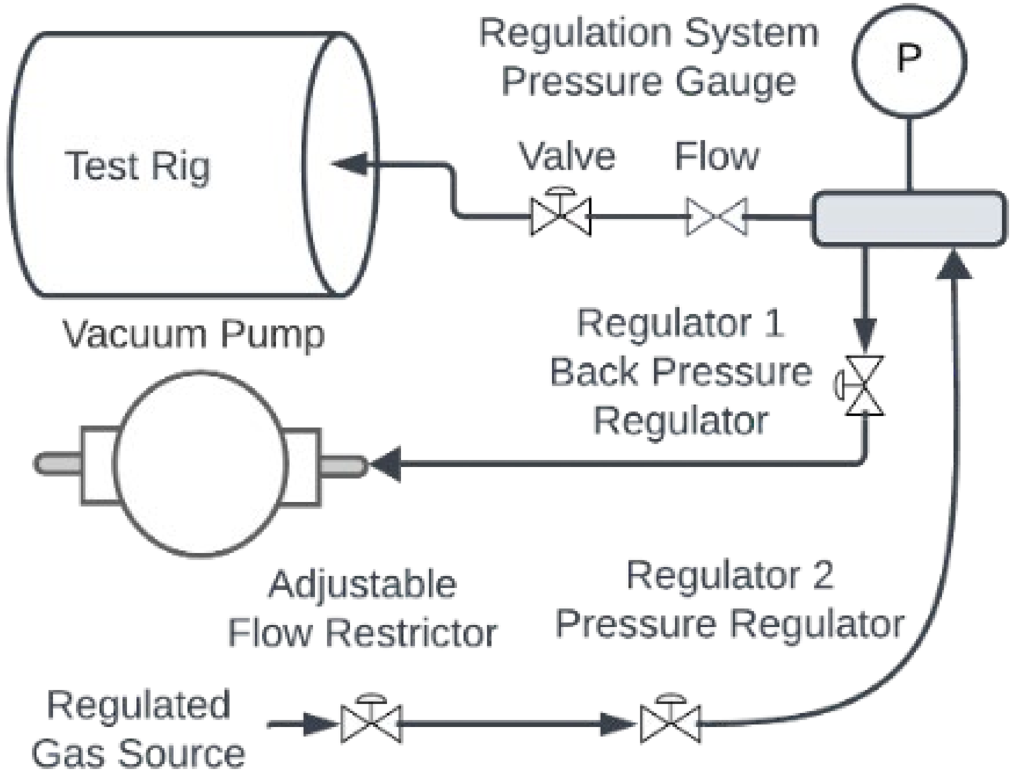
- Regulator 2 opens and Zero-Grade Air restores the pressure

Performance is determined by:

- The spring loading of the diaphragm
- Pressure-dependent flow rate through the regulators
- Physical temperature of the regulators
- Laboratory temperature and pressure

Other considerations:

- Slow initial increase in the leak-rate around the setpoint
- Pressure at the pump inlet depends on the flow through the system
- The setpoint setting of the two regulators is not unique
- A flow meter helps the user balance the inlet with the outlet flows
- The flow restrictor helps with the inrush or refill flow



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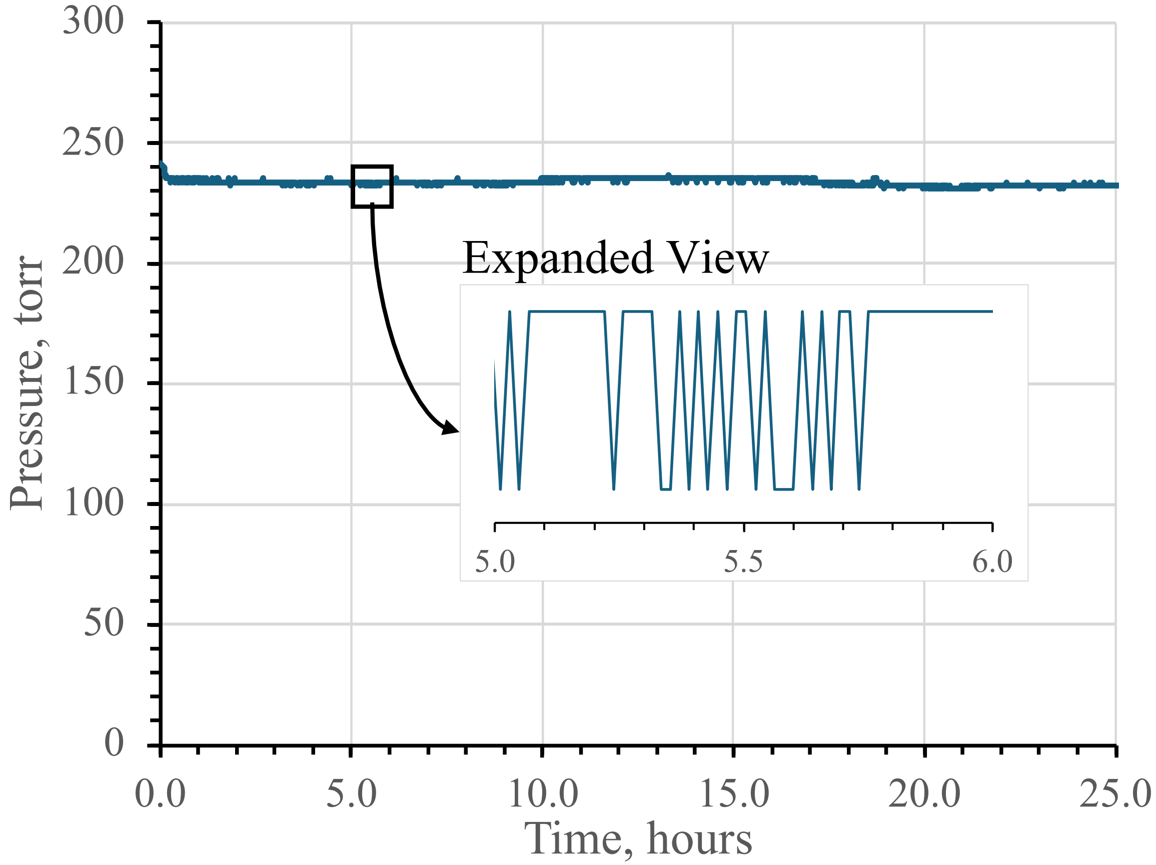
Non-Regenerative TCC Sorbent Testing: Sub-Atmospheric Mechanical Pressure Regulation

System Pressure vs Time
25-hour Section of a 150+ Hour Run



TCC Testing[1]

- 125 g of sieved Ammonasorb II
- Single-bed, 230 mL sorbent cartridge
- Run time of 180 hours
- 200 mL/min injection of nine priority contaminants
- 6 ACFM flow through the system

Pressure Measurements

- Measured before the bed with a NIST-traceable, calibrated TSI flow meter
- TSI pressure accuracy of 8 Torr
- TSI pressure resolution of 0.4 Torr

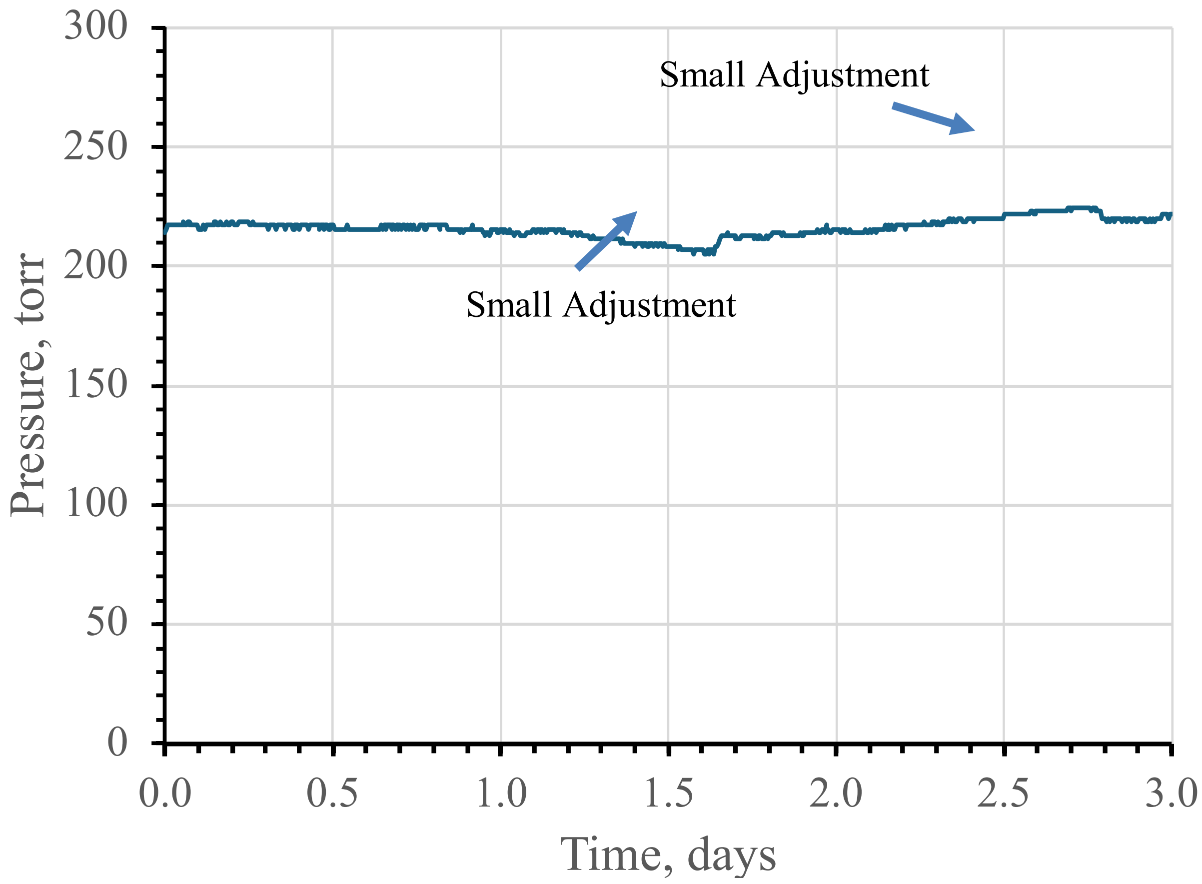
Results

- 234 ± 1 Torr over 25 hours
- Within the measurement resolution at smaller time scales

[1]Kadossov, E., N. Materer, J. Tidwell, M. Teicheira, and S. Shaikh, Evaluation of Traditional and Vacuum-Regenerable Sorbents Exposed to a Multi-Gas Contaminant Mixture in the Trace Contaminant Control Unit, *54th International Conference on Environmental Systems*, Prague, Czech Republic, ICES-2025-42, 2025.

Non-Regenerative TCC Sorbent Testing: Sub-Atmospheric Mechanical Pressure Regulation

72-hour Section of a 150+ Hour Run



TCC Testing[1]

- 125 g of sieved Ammonasorb II
- Single-Bed, 230 mL sorbent cartridge
- Run time of 180 hours
- 200 mL/min injection of nine priority contaminants
- 6 ACFM flow through the system

Results

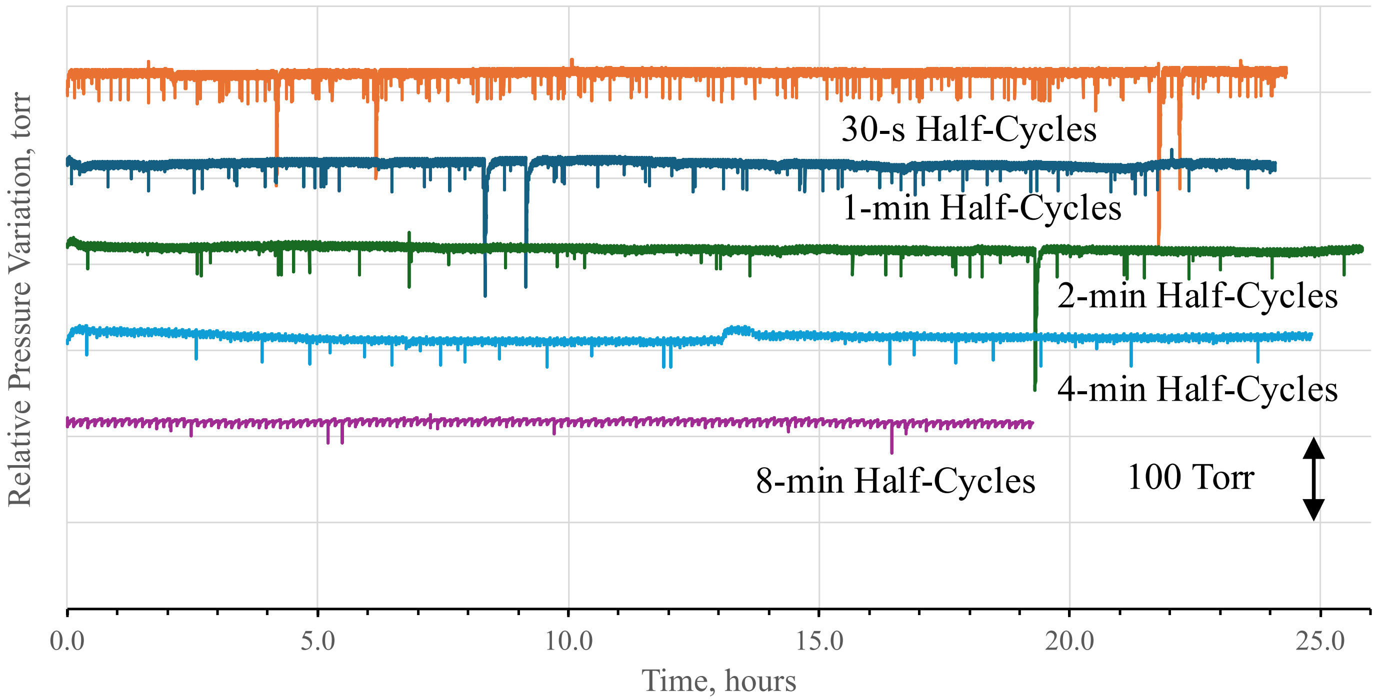
- Pressure regulation is good
- 220 ± 4 Torr
- A longer drift is visible over time

Small adjustments of the back-pressure regulator were required to compensate for changing laboratory conditions.

[1]Kadossov, E., N. Materer, J. Tidwell, M. Teicheira, and S. Shaikh, Evaluation of Traditional and Vacuum-Regenerable Sorbents Exposed to a Multi-Gas Contaminant Mixture in the Trace Contaminant Control Unit, *54th International Conference on Environmental Systems*, Prague, Czech Republic, ICES-2025-42, 2025.

Regenerative TCC Sorbent Testing: Sub-Atmospheric Mechanical Pressure Regulation

Sub-atmospheric pressure regulation during regenerative TCC sorbent testing



*For visibility, data is offset. Each y-axis grid spacing is 100 torr.

TCC Testing[1]

- ~72 g of sieved Airosorb
- Single-bed, 230 mL sorbent cartridge
- Run time of 1-3 8-hour EVAs
- 200 mL/min injection of nine priority contaminants
- 6 ACFM flow through the system

Initial Assessment

- Pressure regulation is good
- Drift minimized by manual adjustment

[1]Kadossov, E., N. Materer, J. Tidwell, M. Teicheira, and S. Shaikh, Evaluation of Traditional and Vacuum-Regenerable Sorbents Exposed to a Multi-Gas Contaminant Mixture in the Trace Contaminant Control Unit, *54th International Conference on Environmental Systems*, Prague, Czech Republic, ICES-2025-42, 2025.

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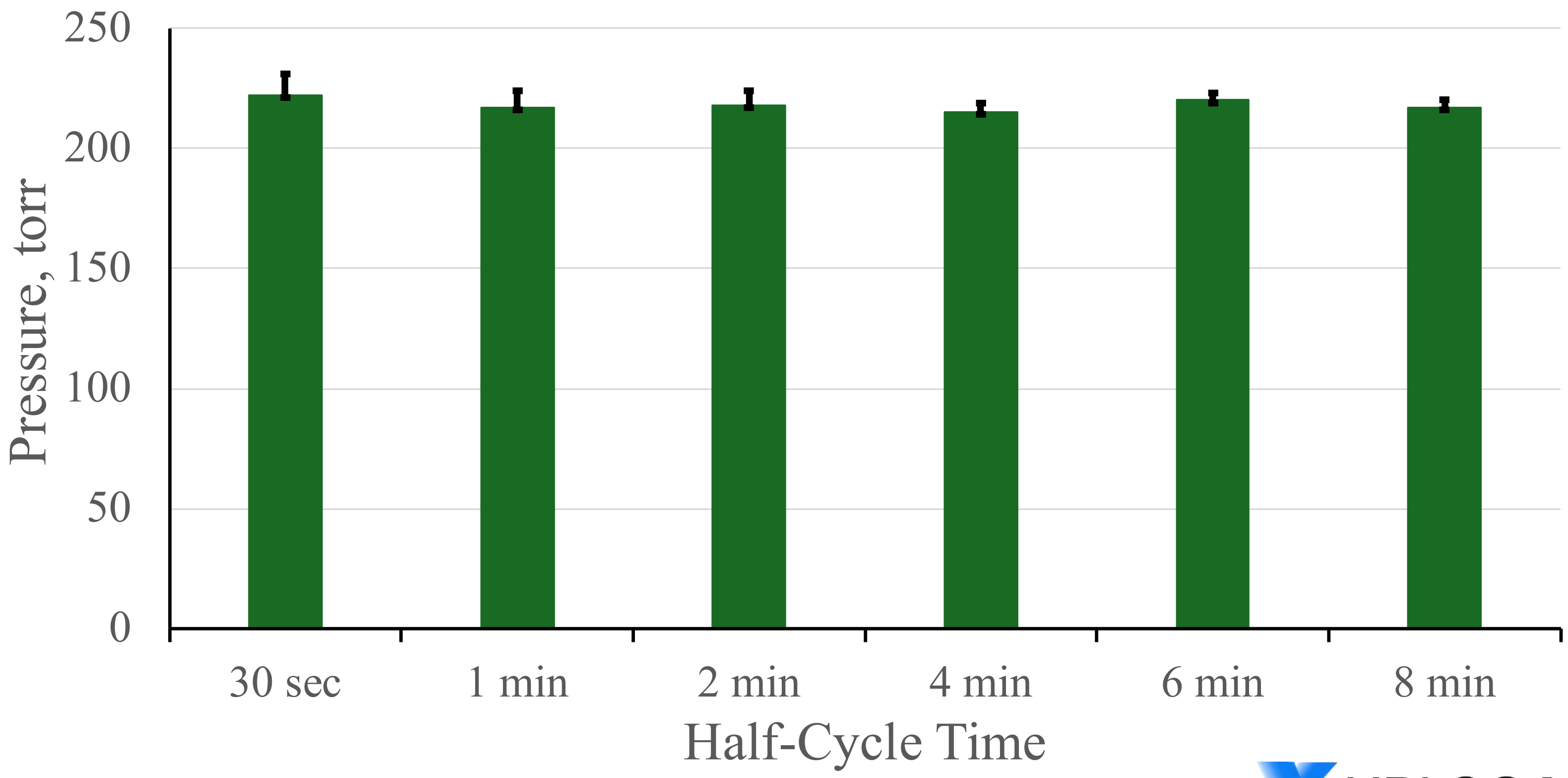
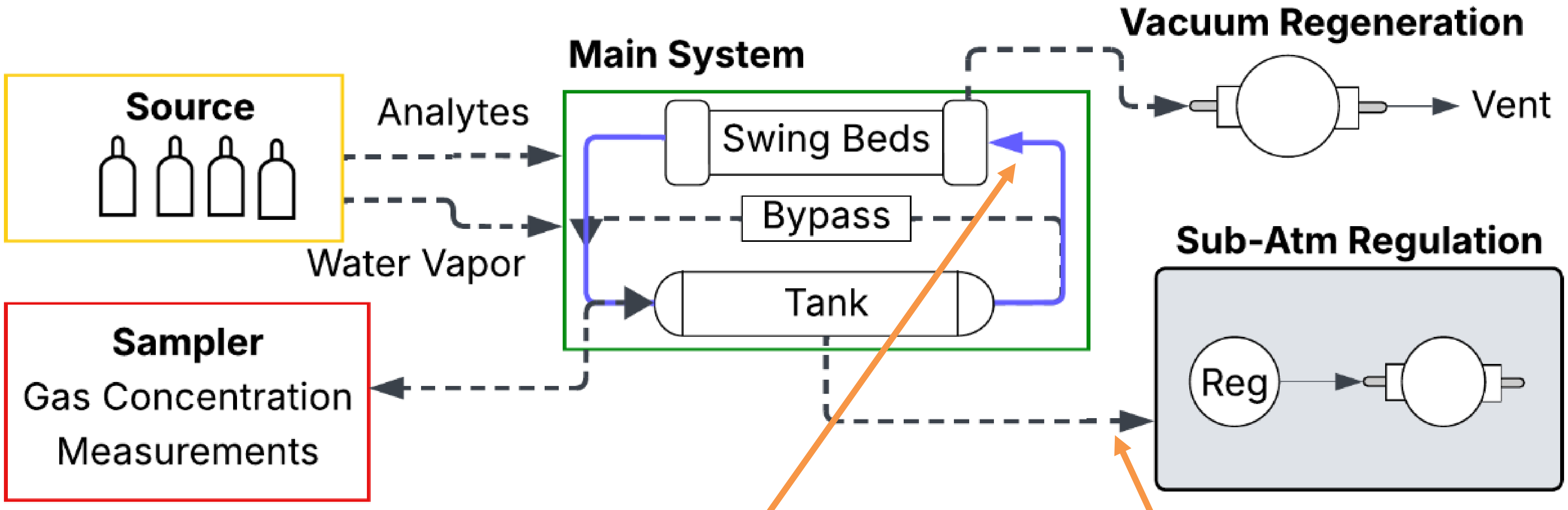
Regenerative TCC Sorbent Testing: Sub-Atmospheric Mechanical Pressure Regulation Results

Average measured pressure and its variation (standard deviation) as functions of the half-cycle time during regenerative Airosorb TCC sorbent evaluations

Half-Cycle	Run Time
30 sec	24 hours
1 min	24 hours
2 min	26 hours
4 min	24 hours
6 min	8 hours
8 min	19 hours



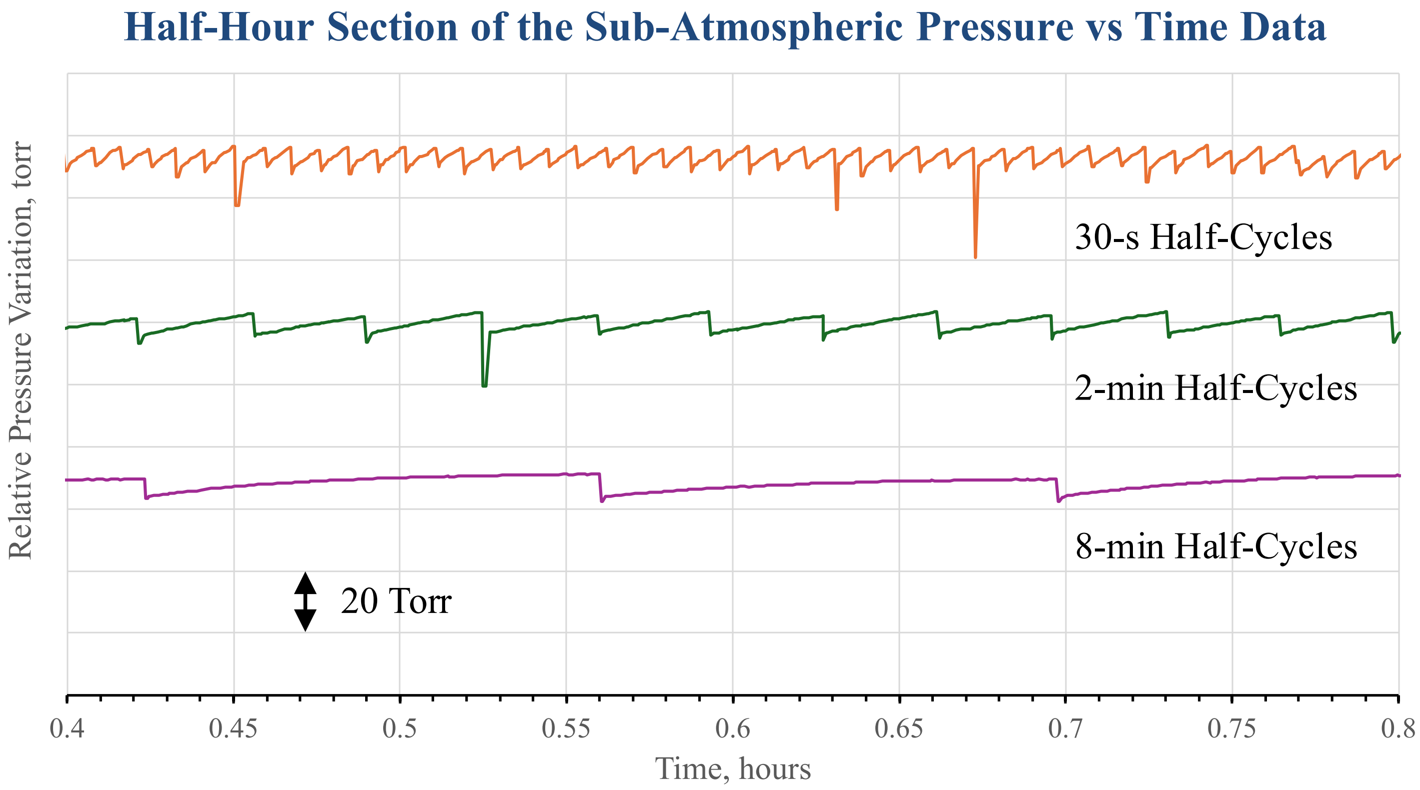
Simplified Illustration of the XploSafe TCC and RCA Test Rigs



Pressure was recorded here
Un-buffered by the volume of the tank

Pressure here did not vary significantly due to buffering by the tank volume

Regenerative TCC Sorbent Testing:
Sub-Atmospheric Mechanical Pressure Regulation – A Closer Look



*The plot starts 7 hours into the experiment.
The data is offset for visibility. Each y-axis grid space is 20 torr.

Each "Swing" cycle is the loss of ~1 L due to regeneration

Start
- Bed is partially refilled
- Fast decrease when bed opens
- Sometimes downward spikes appear

Mid-Cycle
- Slow pressure increase (Regulator 2)

End
- Pressure levels-off for longer cycles

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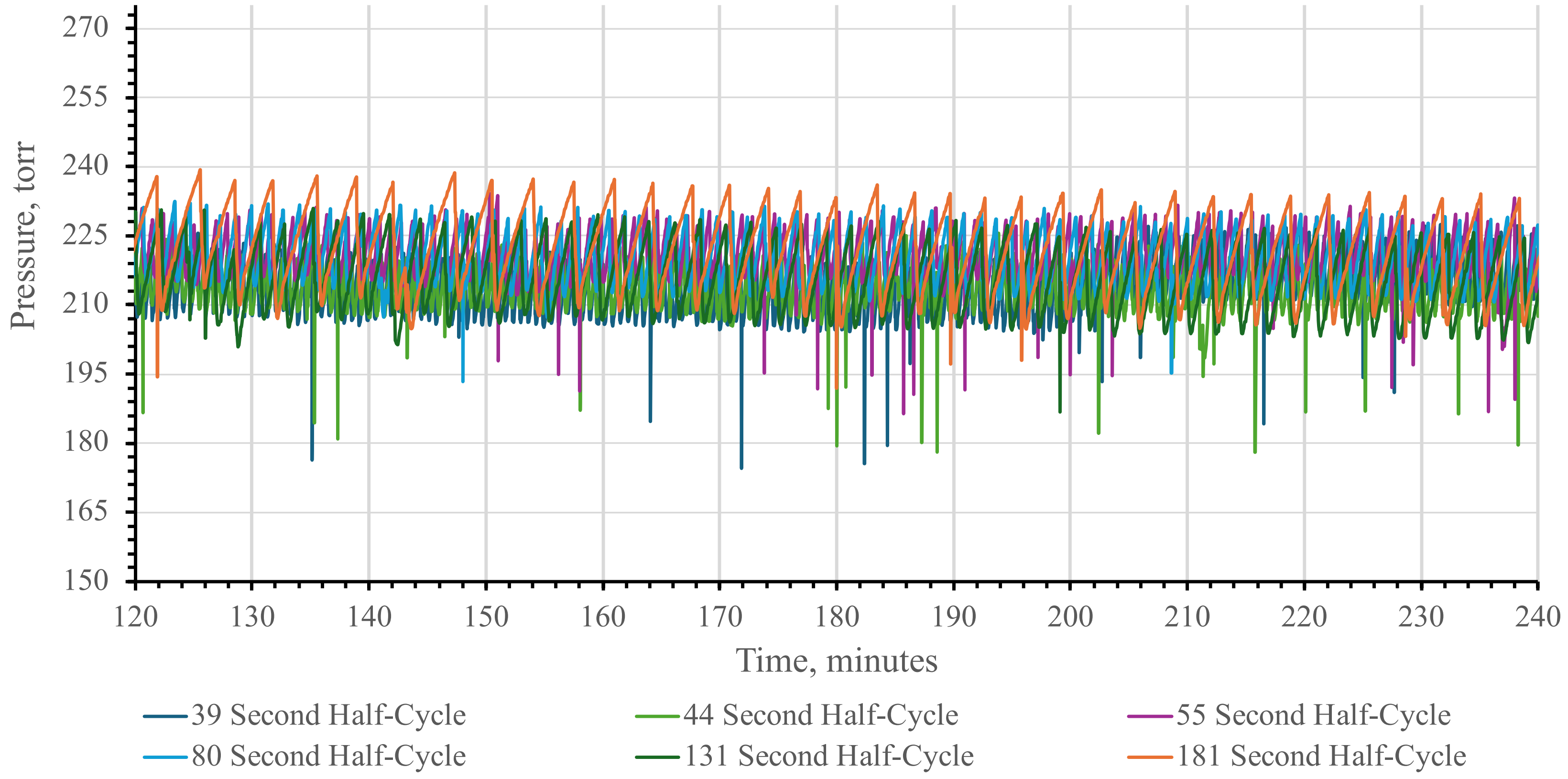
RCA Adsorbent Testing: Sub-Atmospheric Mechanical Pressure Regulation Results

Steady-state sub-atmospheric pressure regulation during an 8-hour simulated EVA at metabolic rates between 800 and 3000 BTU/h with different half-cycle times, each one corresponding to a different metabolic rate.



More Challenging

- Xplo-SA9T
- Variable cycling
- Large inlet-flow of CO_2 and H_2O

Decent Performance

- Standard deviation ranging from 6 to 10 torr

Each Data Set Required Different Regulator Settings

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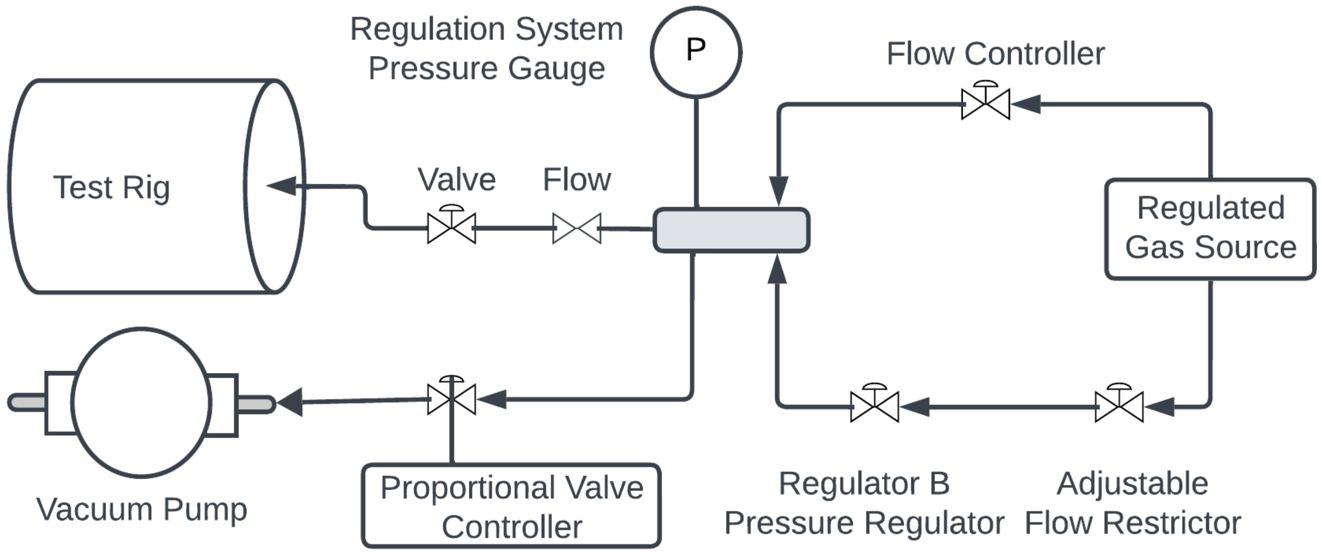
Electronically Controlled Sub-Atmospheric Regulation

Electronically Control

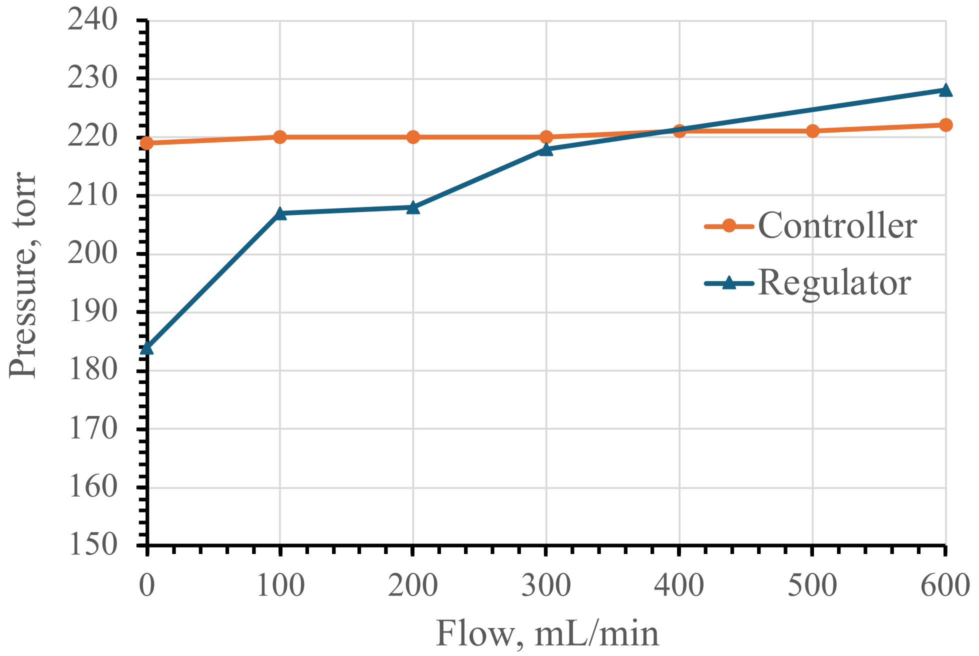
- No long-term drift due to changing laboratory conditions
- Eliminates manual adjustments for different cycle times and inlet loads

Schematic of the Electronically Controlled Regulation

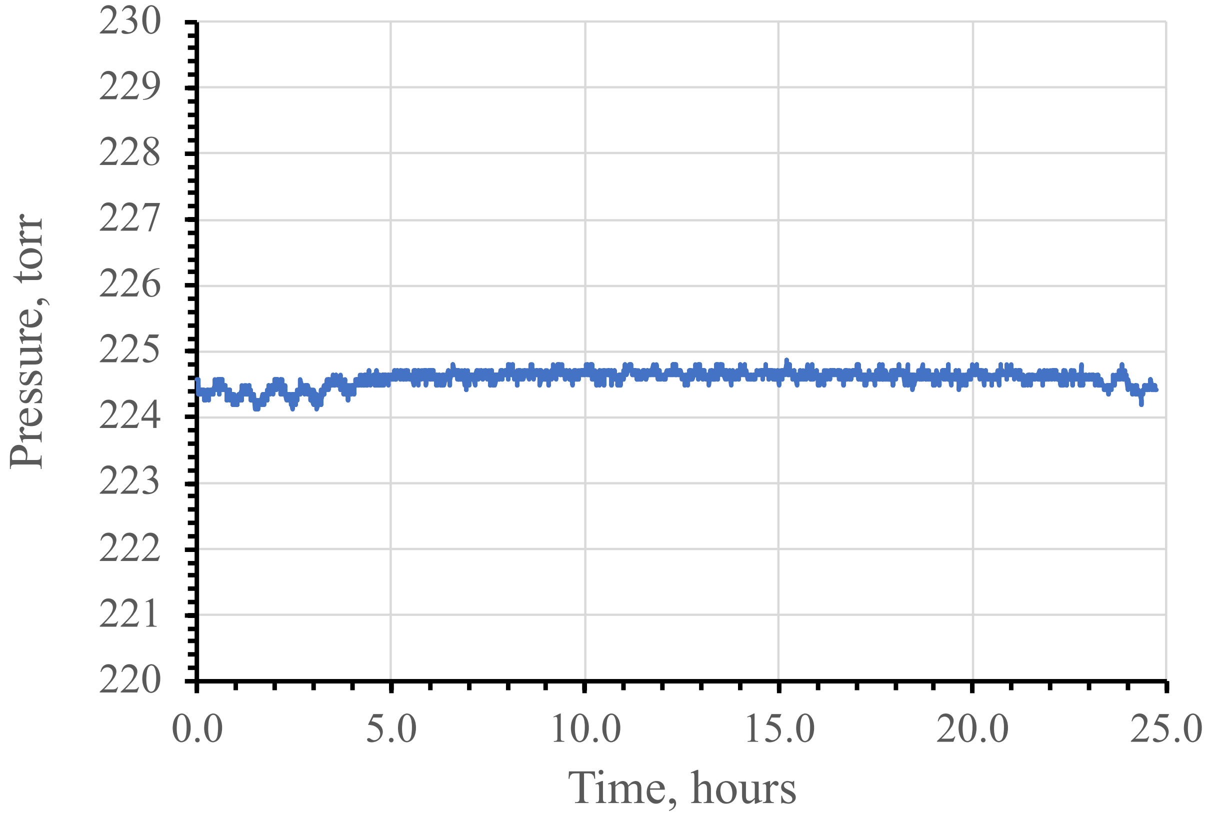


Additions

- Proportional valve for sub-atmospheric regulation
- Flow controller for controlled refill
- PID controller automatically adjusts for changing inlet flows



Electronically Controlled Sub-Atmospheric Regulation: Non-Regenerative Test



Simulated Non-Regenerative Test

- Non-cyclic test
- 25-hour run
- Input flow 200 mL/min
- Average pressure of 224.6 ± 0.2 torr

Key Points

- No long-term drift
- No readjustments

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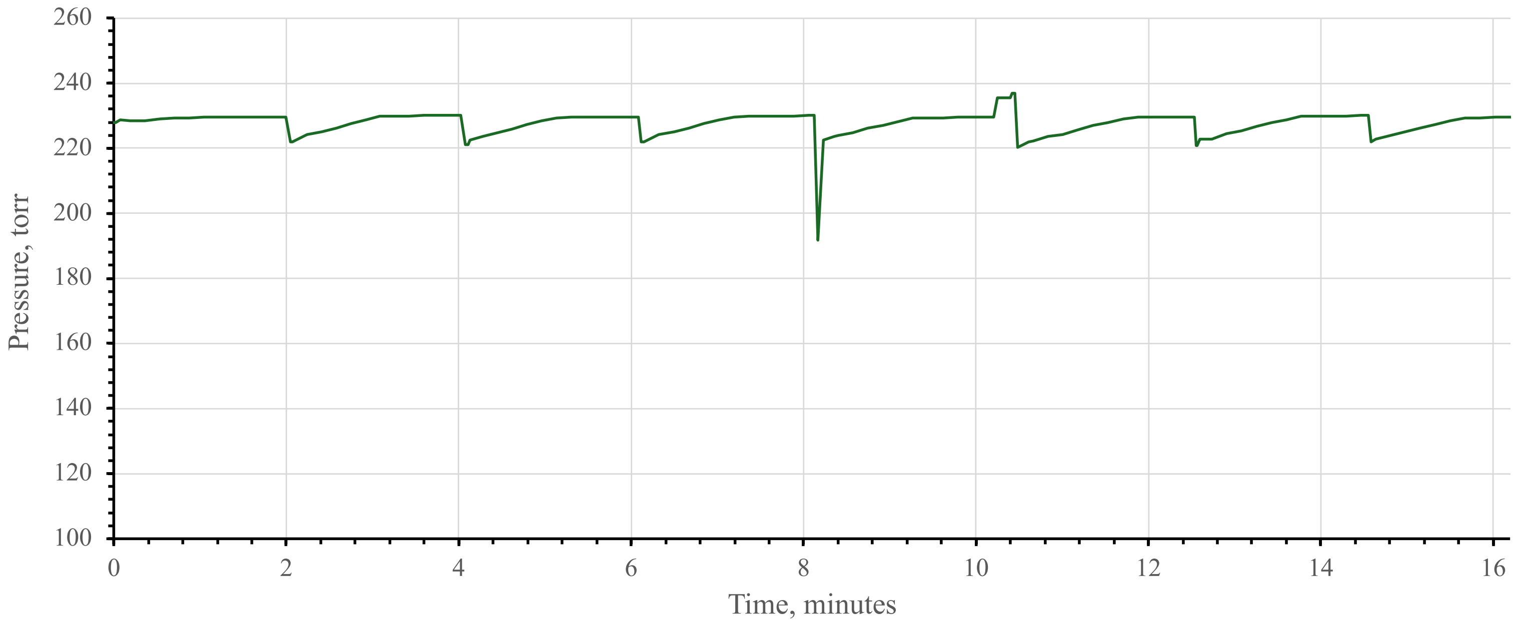
Electronically Controlled Sub-Atmospheric Regulation: Regenerative Testing

Selected 2-min Half-Cycles



Simulated Regenerative Testing

- 2-min half-cycle
- Section from a longer run
- Input flow 200 mL/min
- Average pressure 228 ± 5 torr

Conclusions

Tests were conducted under Lunar EVA conditions

Sub-atmospheric Mechanical Pressure Regulation
Pressure variations were under 10 torr for all conditions tested

- 150+ hour non-regenerative TCC sorbent evaluation
- Several 24-hour regenerative TCC sorbent evaluations
- Several 8-hour RCA swing-bed adsorbent evaluations

Electronically Controlled Sub-Atmospheric Regulation

- No long-term drift
- Eliminates manual adjustments due to different cycle times and gas loads

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Questions?

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