Designing a Propylene-Glycol Coolant Servicer System for Gateway's Internal Active Thermal Control System

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EC6

Thermal Systems

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Overview

- Introduction to our Team
- Introduction to Coolant Servicing in an Active Thermal Control System
  - Previous Work on the International Space Station
  - Coolant Servicer System (CSS) Introduction
- CSS Preliminary Design
- CSS Risk Mitigation Testing
  - Key Performance Parameters (KPPs)
  - Gas Trap Performance Testing
  - Drill Pump Testing
- Summary of Forward Work

EC6 (Team) Overview

- Lyndon B. Johnson Space Center
- Engineering Directorate
- Crew & Thermal Systems Division
- Thermal Systems Branch
- Technology and Special Projects Team

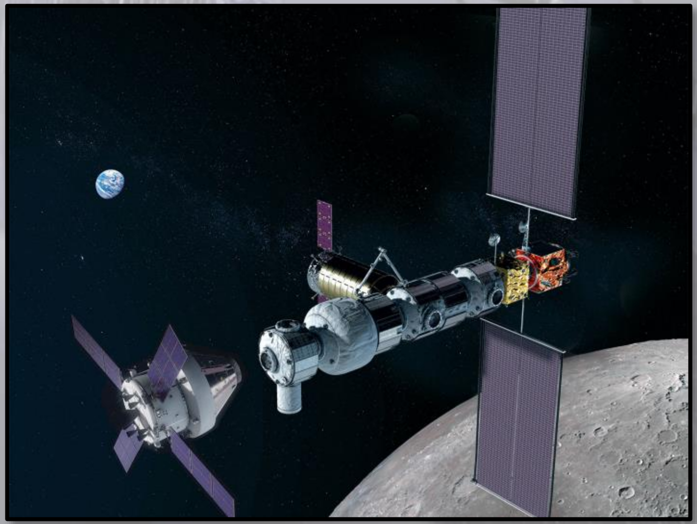
Integrated Space Environment Testing

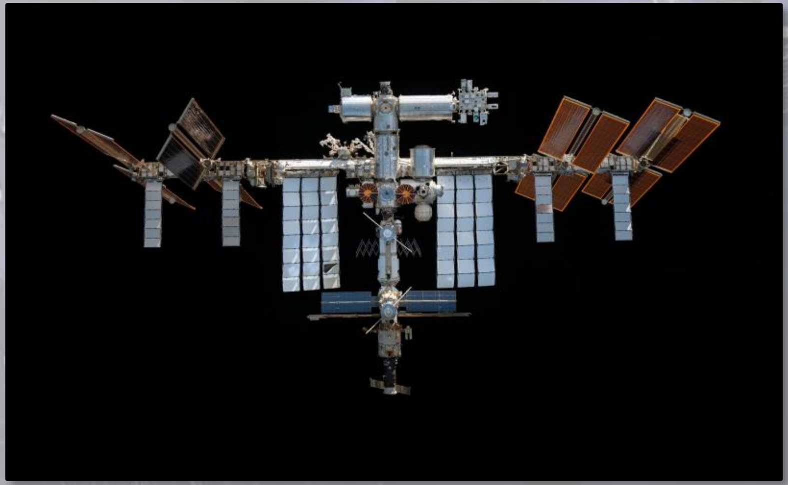
Government Furnished Equipment / Flight Hardware

Technology Development

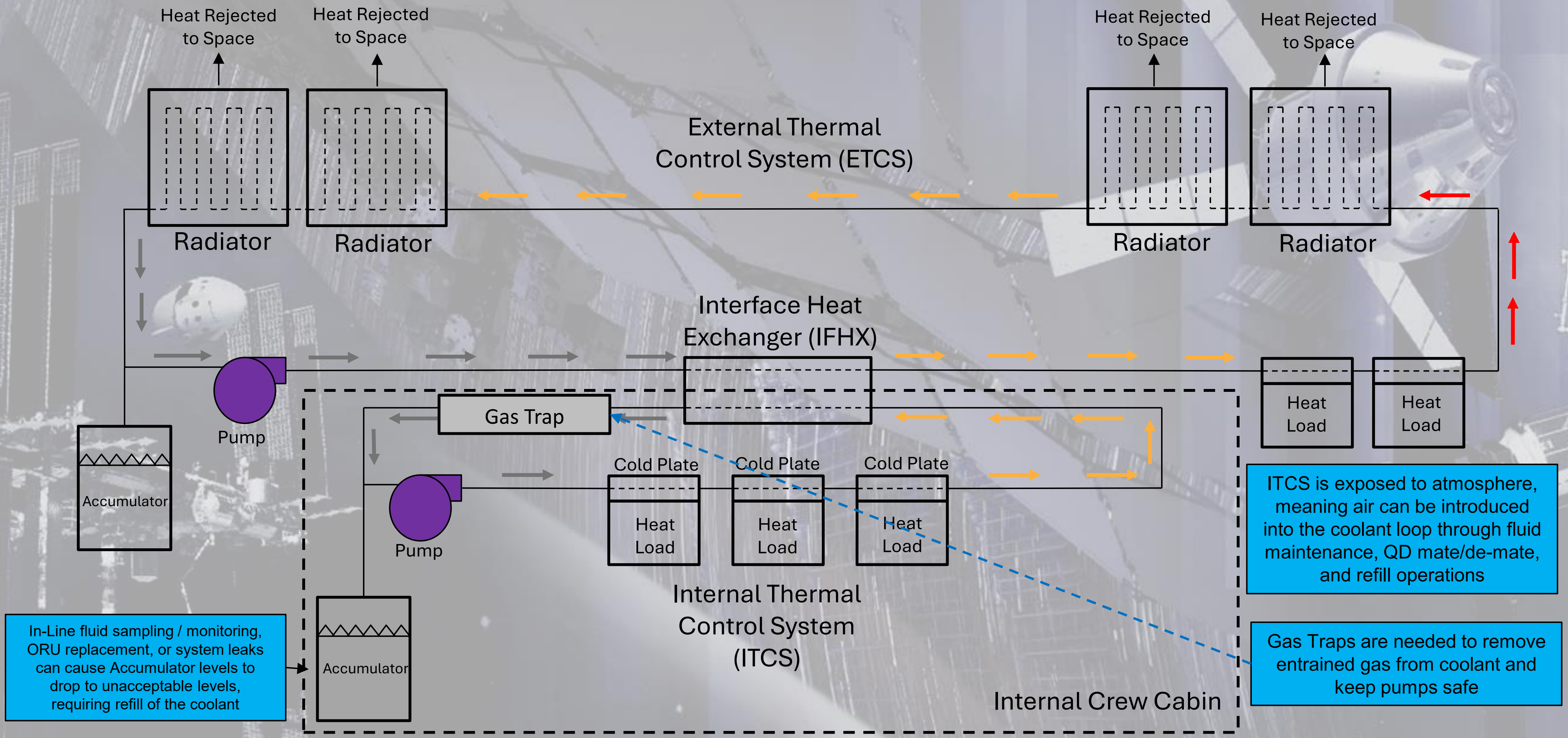
Active Thermal Control Systems (ATCS)

- Human Spaceflight missions (amongst other applications) have high and variable heat loads that necessitate tunable heat rejection capability to keep set points inside the crew cabin safe and habitable for equipment and crew.
- Active Thermal Control Systems are primarily pumped fluid loops that complete this function, and are used on landers, rovers, crew capsules, and space stations / habitats
- The Gateway Space Station was a planned Lunar Orbital Outpost for crew habitation and logistics.
    - The scope of the work in this paper had to do with the Gateway Active Thermal Control System, but the hardware carries applications to any customer building a long-term human habitat in space.





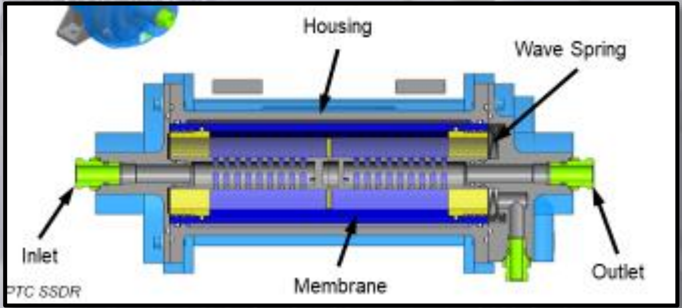
Servicing a Dual-Loop Active Thermal Control System



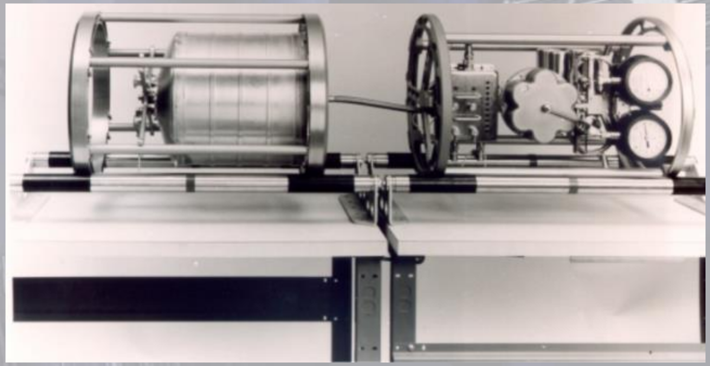
Coolant Servicing – Previous Work

- The International Space Station (ISS) possesses a gas trap in the Internal Thermal Control System to prevent long-term damage to pump ORUs.
- In the Orion Spacecraft Crew Module, every time the crew member plugs in spacesuit umbilicals, a little bit of air is introduced into the liquid cooled water garment loop.
  - Orion gas Trap is attached for 5 minutes after every time crew plugs in to remove this gas.
- **Both gas traps are only useful with water as the working fluid.**
- **No Gas Trap has been certified to work in human spaceflight for non-water working fluids.**
  - 40/60 Propylene-Glycol Water is used on the Gateway Internal Active Control System (IATCS).
- Additionally, the ISS has a Fluid Servicing System (FSS) that can conduct refill of the ITCS coolant.

ISS Gas Trap



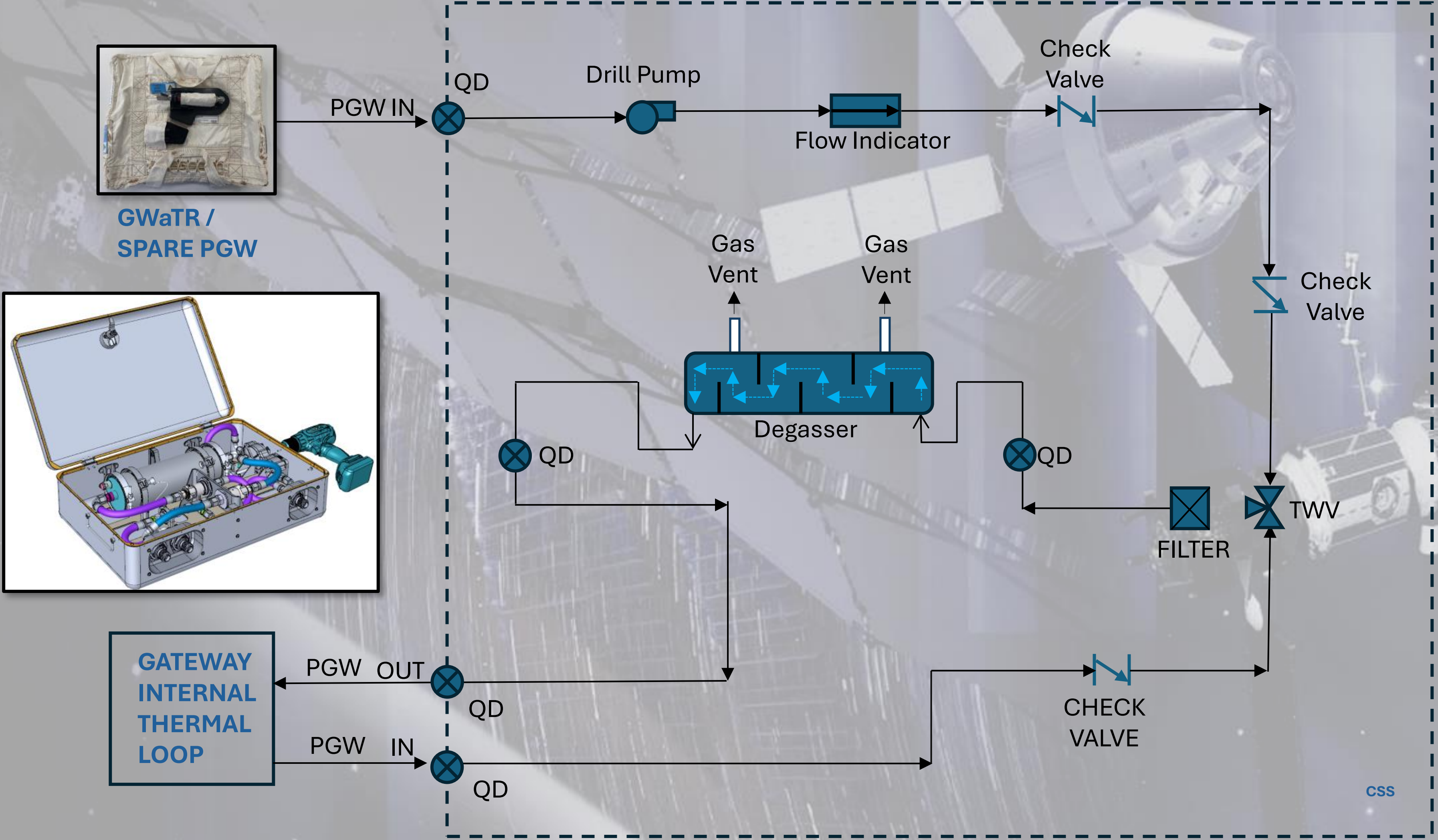
Orion LCG gas trap



ISS FSS Tanks Controlled to Fluid Control / Pump Assembly

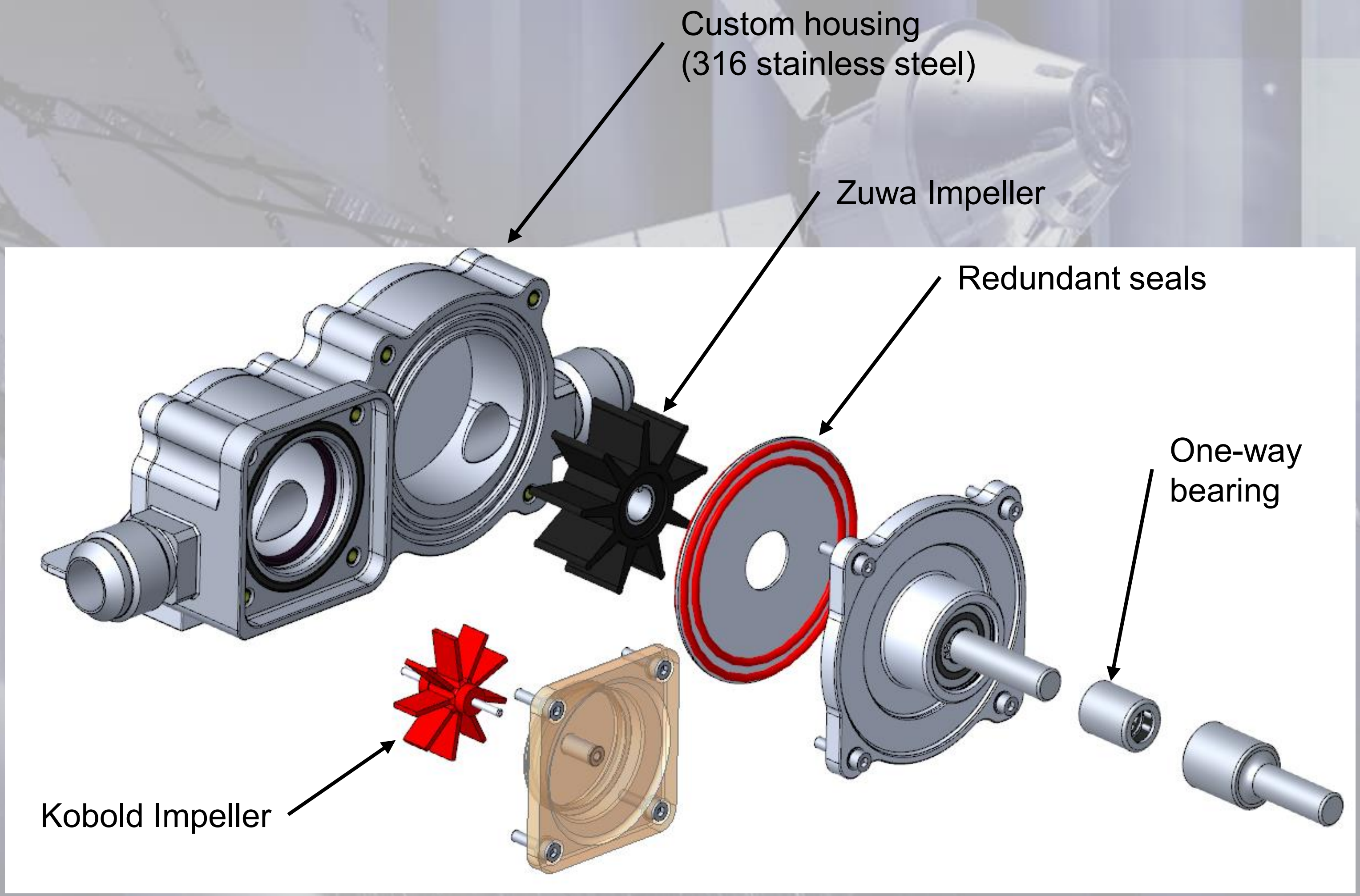
Coolant Servicer System (CSS) Flow Diagram

- The EC6 Technology and Special Projects team was tasked create a flight hardware assembly that conducts gas removal and fluid refill of the Gateway Internal Active Thermal Control System (IATCS)
- <u>Goal:</u> Create a low mass / low volume assembly capable of modularly plugging into the loop and conducting degas / refill as needed.
- <u>Additional Goal:</u> Make the system "electronics free" to reduce complexity and cost.



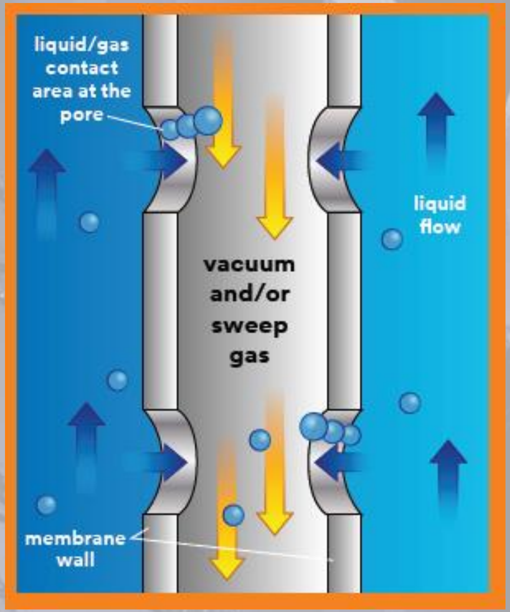
Coolant Servicer System (CSS) Preliminary Design

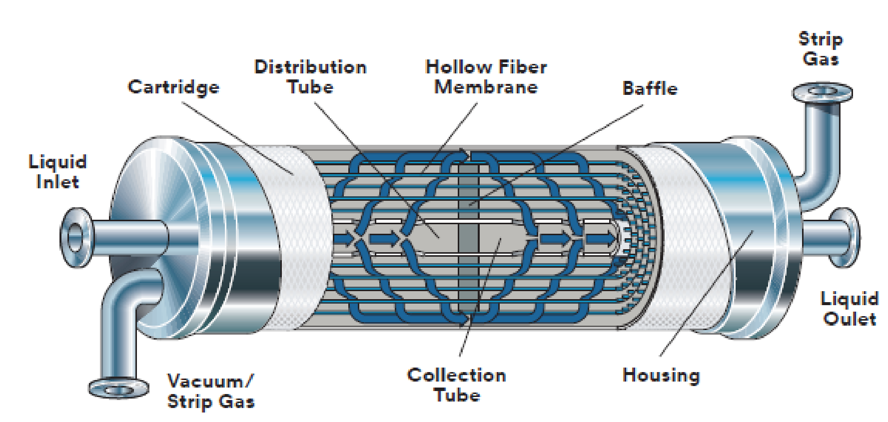
- COTS:
  - Zuwa Combistar Viton impeller
  - Zuwa Combistar pump geometry and design
  - Kobold flow indicating paddle wheel
  - Kobold flow indicator geometry and design
- Custom housing
  - Adds redundant soft seals at all seal locations (Gateway Requirement)
  - Reduces footprint and adds mounting options
- One way bearing on pump drive shaft makes it impossible to pump wrong direction



Coolant Servicer System (CSS) Preliminary Design

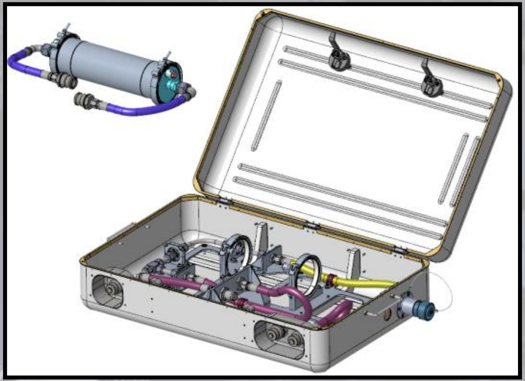
- Commercial-Off-The-Shelf (COTS) Degasser – 4x13 Thermo-Fischer Superphobic Membrane Gas Separator
  - Relies on gas permeable membrane to separate gas from pressurized liquid rather than porous structure.
  - Similar operation to the ISS gas trap, but Superphobic membrane provides better performance for low surface tension fluids like PGW.
- Standard operation
  - Two-phase propylene-glycol water enters the liquid inlet ports and flows through multiple baffles that force the fluid around the shell side of the superphobic membrane tubes.
  - Pressure gradient between ~50psia fluid loop and gas side (atmospheric space station crew environment) works as a driving force to pull bubbles across membrane.
  - Air exits out of the gas outlets

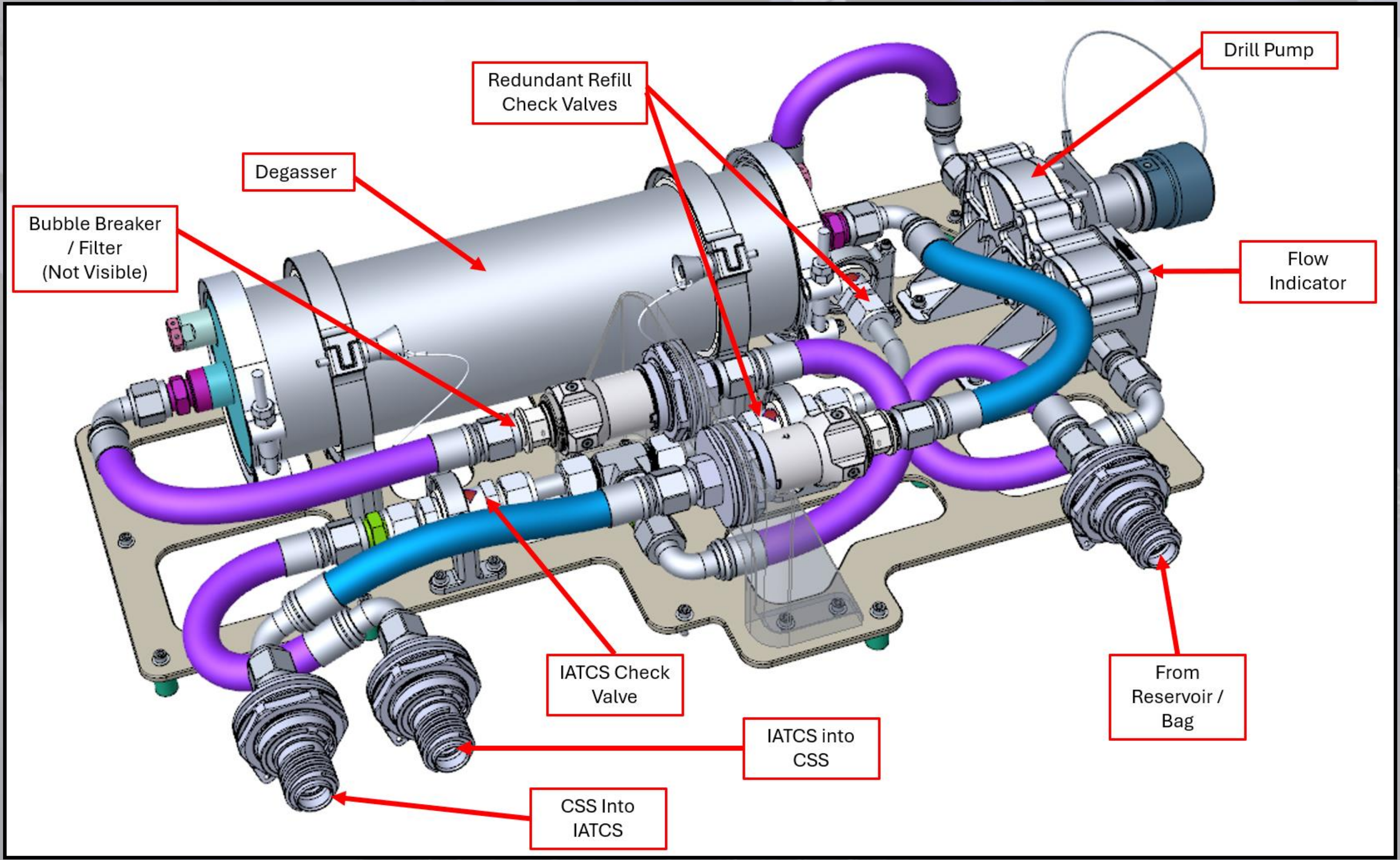




Gore Protective Vent

Coolant Servicer System (CSS) Preliminary Design

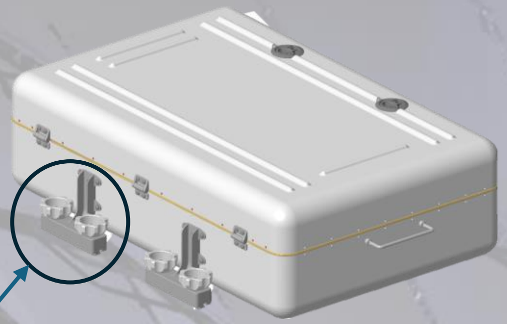


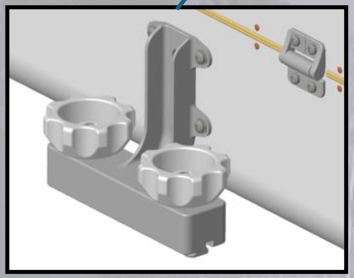


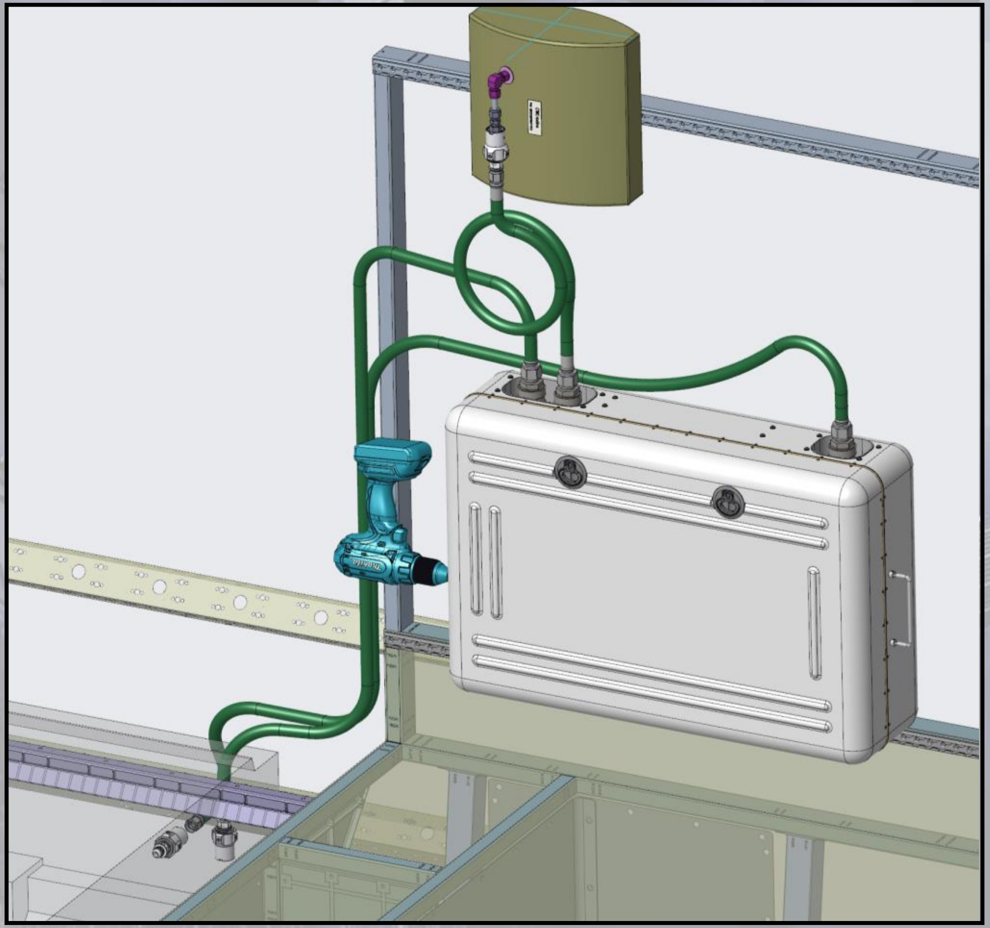
- PTFE Convoluted Flex Hoses allow for CSS gas trap to be replaceable with quick disconnects.
- System is tightly integrated into enclosure that panel mounts QDs and IVA drill shaft
- Aluminum plate mount allows for secure connection of the CSS fluid assembly to the enclosure.

Coolant Servicer System (CSS) Preliminary Design

- 32” x 21” x 5.5” Aluminum extruded COTS Enclosure
  - Uses feet that secure CSS to seat track (similar to ISS)
  - Friction hinges hold lid in any position when open.
  - Stiffening ribs that support plumbing.
- Flex hoses and quick disconnects connect the CSS to the fluid storage bag and HALO IATCS







CSS Key Performance Parameters (KPPs)

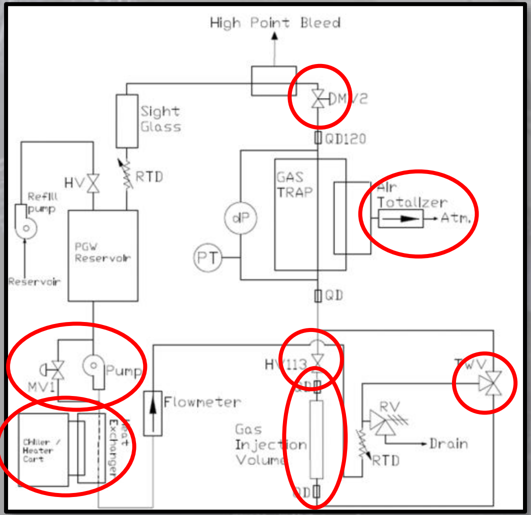
- The project (at time of manuscript writing) was in between System Requirements Review (SRR) and Preliminary Design Review (PDR), meaning there is a list of performance requirements that the CSS must meet.
- The Key Performance Parameters (KPPs) shown to the right were the high-risk performance parameters that required "risk mitigation" testing on the COTS gas trap and drill pump.

	Key Performance Parameter (KPP)	Value	Rationale
1	Degasser Hydrostatic Pressure Maximum	108psia (744 kPa (abs))	1.5 Times the maximum Gateway accumulator set point, 72psia (496 kPa (abs)).
2	Degasser Pressure Drop	5 psid (34.47 kPa(d))	No hard requirement set by Gateway, but it is assumed to be a maximum acceptable value when compared to the IATCS pump head.
3	Gas Removal Capability	Capable of degassing loop to $0.024in^3$ (0.93mL) remaining volume	Assumed to be the smallest bubble diameter that could vapor lock an IATCS pump.
4	Drill Pump Minimum Flowrate capability	0.53gpm (2 L/min)	Requirement given from Gateway to decrease reliance on crew time.
5	Drill Pump Head Pressure	55psia (379.2 kPa)	Allows the drill pump to recharge the accumulator to the maximum nominal accumulator set pressure.
6	Touch temperature hazards	No unlimited bare skin contact between 32°F (0°C) and 113°F (45°C)	Touch temperature limits given by Gateway Program.

CSS Gas Trap Risk Mitigation Testing – Gas Trap Performance

- Degasser Testing Goals:
  - Measure gas removal performance in Gateway-like IATCS conditions
    - Pressures from 25psia-55psia (172.4-379.2 kPa)
    - Flowrates up to 800lbm/hr (369.2kg/hr)
    - PGW temperatures from 39F to 104F (4C to 40C)
    - Air bubble (slug) sizes from 0.08in3 to 3.9in3 (2mL to 64mL)
  - Measure pressure drop of the degasser at Gateway-like conditions (full flowrate range)
    - Need to verify that the pressure drop won't tax the Gateway IATCS pump
  - Verify Maximum Design Pressure (MDP) of degasser to verify it can meet Gateway requirements
    - Integration at the suction side of the IATCS pump guarantees the CSS will be exposed to IATCS accumulator (bellows tank) pressures.

CSS Gas Trap Risk Mitigation Testing – Gas Trap Performance



1. Turn on Pump and use MVs to configure flowrate and pressure.

2. Use Chiller / HX to configure desired loop temperature

5. Remove sight glass assembly using QDs and pour out desired air slug volume, then reassemble in loop

7. Use Air flowmeter to determine gas trap efficiency / breakthrough

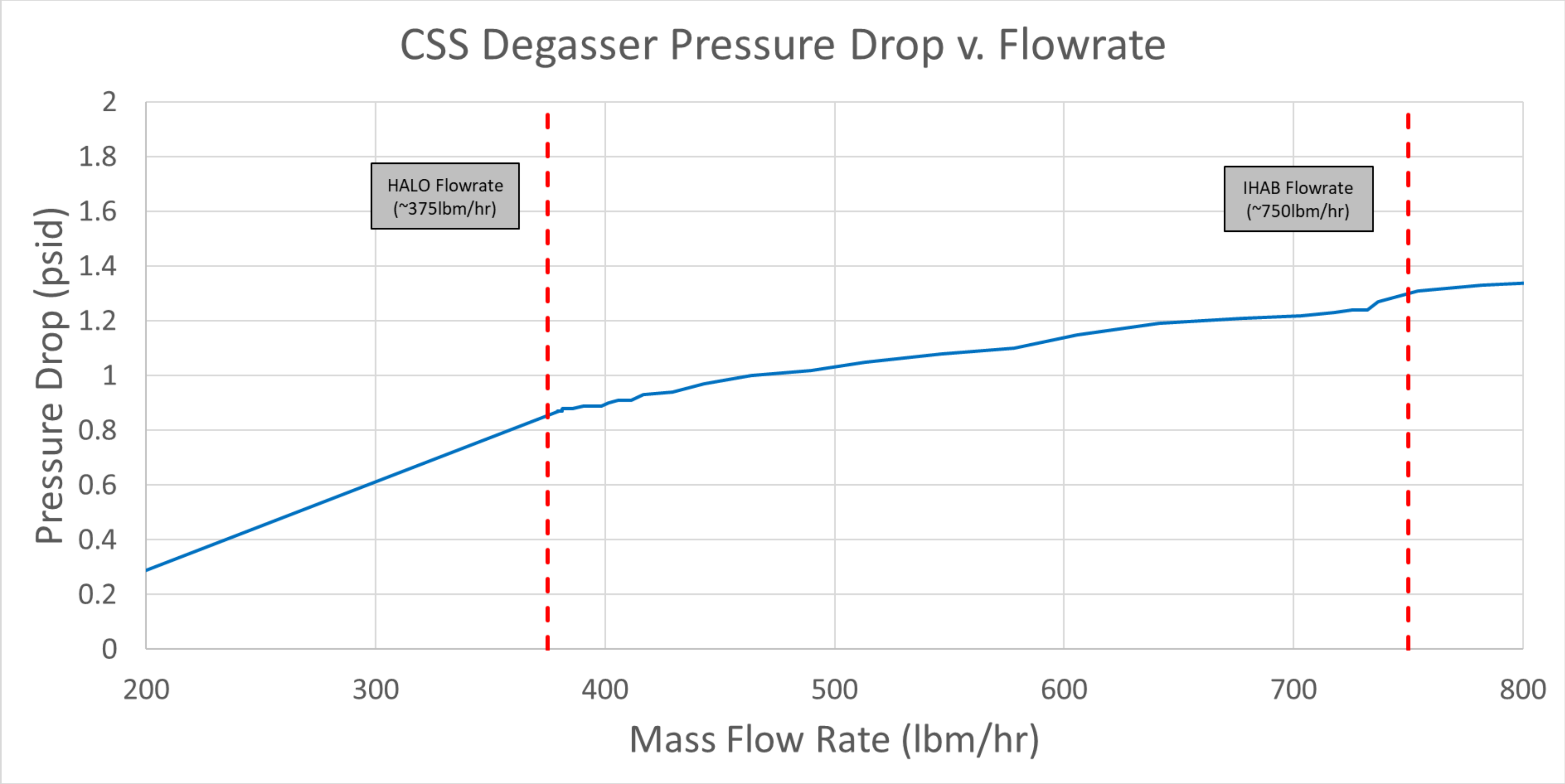
$$Gas\ Removal\ Efficiency\ (\%) = \frac{Gas\ Collected\ (From\ Air\ Totalizer)}{Gas\ Injected} * 100\%$$

3. Ensure 3-way valve is bypassing gas injection

6. Open ball valve and flip 3-way valve at the same time to flow air slug into gas trap

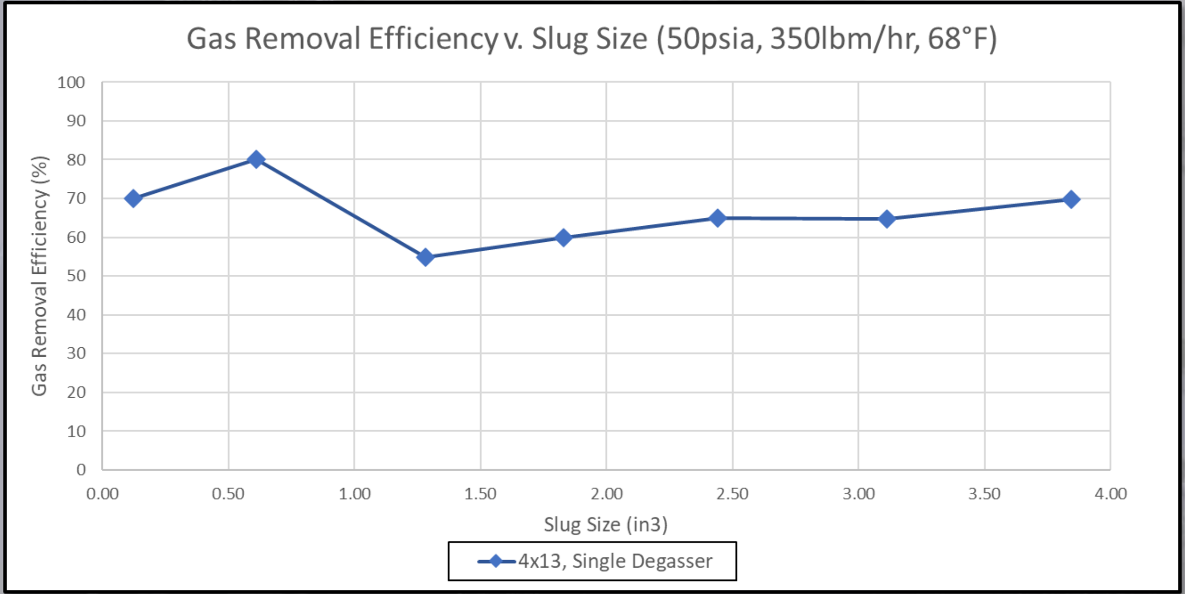
4. Ensure ball valve in front of gas injection is SHUT

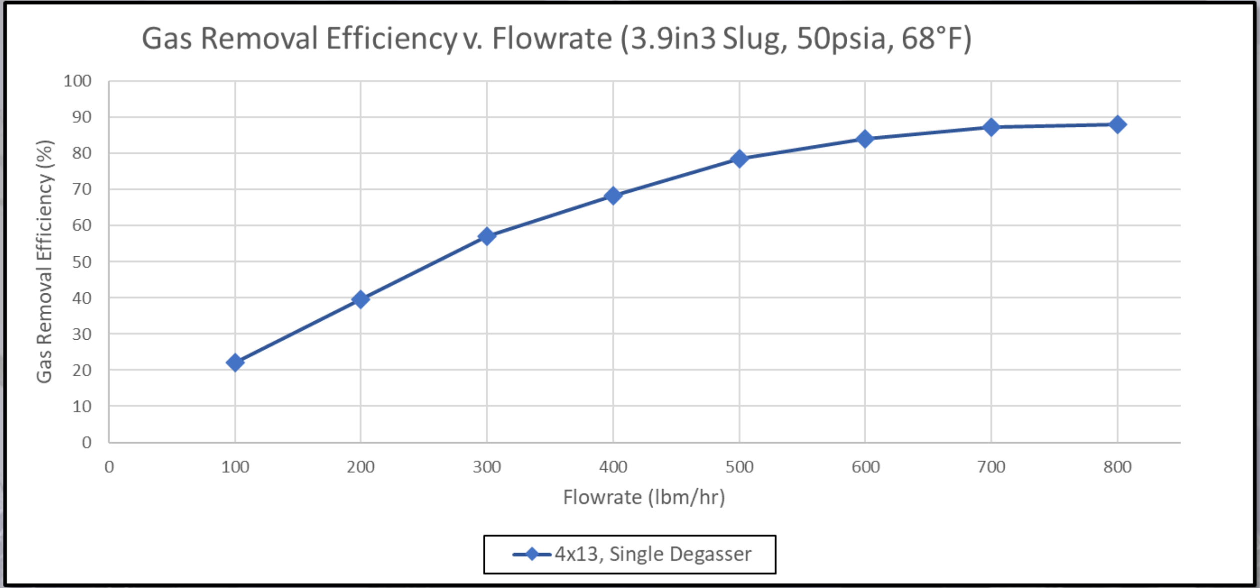
CSS Gas Trap Risk Mitigation Testing – Gas Trap Performance



- *Takeaway* – Pressure Drop below 1.2psid at worst-case flowrates is acceptable for the Gateway Coolant Loop (and most applications)

CSS Gas Trap Risk Mitigation Testing – Gas Trap Performance



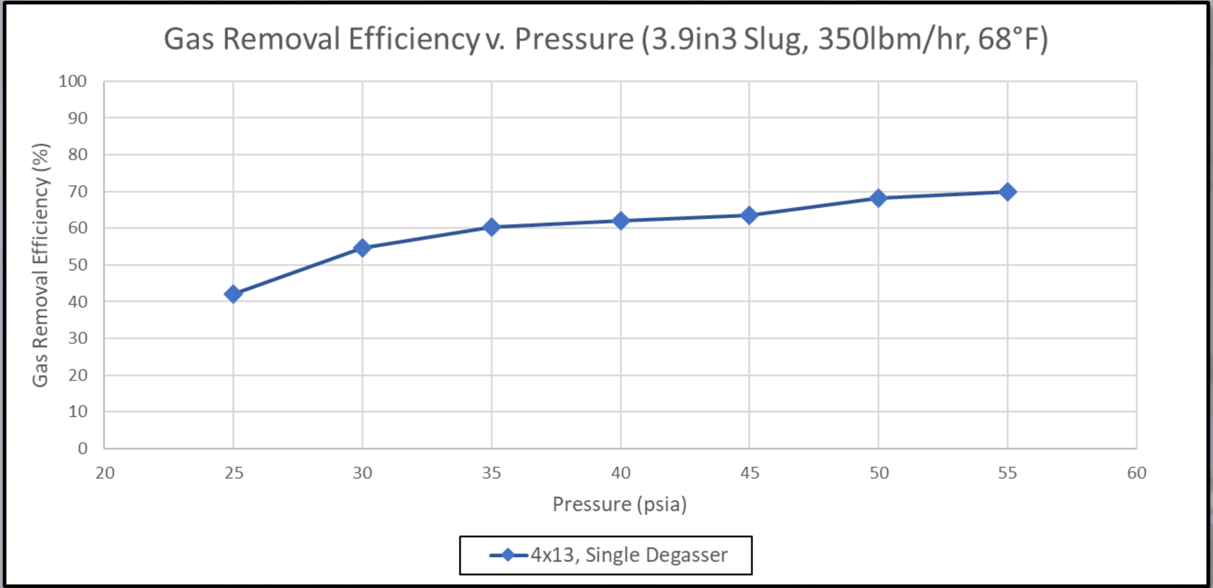


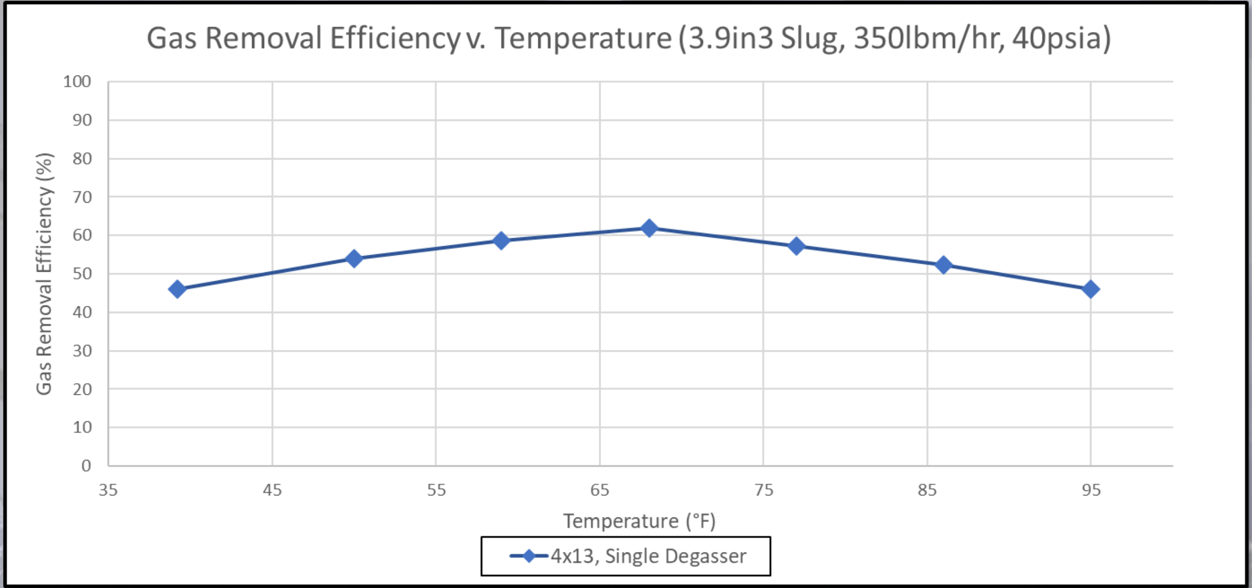
- There was not a clear relationship between single-pass gas removal efficiency and bubble / slug size.
- High efficiency at small bubble sizes (2mL) indicate that the degasser can degas a loop to at least 0.39mL of total air if given enough time to recirculate a bubble multiple times:

$$2mL - (2mL * 70\%) = 0.39mL$$

- Gas removal efficiency increased proportionally with an increase in mass flowrate of PGW.
  - Upon talking to Thermo-Fischer, the possible reason for this could be boundary layer breakdown of the within the degasser membrane bundle, causing better exposure of the bubble to the membrane at higher flowrates

CSS Gas Trap Risk Mitigation Testing – Gas Trap Performance





- Gas Removal Efficiency increased with an increase in PGW loop pressure
  - Increasing pressure of the PGW loop increases the pressure gradient across the membrane, increasing the driving force for gas removal.

- Gas Removal Efficiency was highest at ambient temperatures but tapered off slightly at lower and higher temperatures in the 4C to 35C temperature range.

CSS Gas Trap Risk Mitigation Testing – Gas Trap Hydrostat

- CSS Requirements Document from Gateway States:
  - The Coolant Servicer System (CSS) shall have a MDP of 108 psig (744.6kPa).

Coolant Temperature	MDP of Gas Trap Membrane (From Vendor Spec Sheet)
20C	90psia
30C	67.5psia
40C	45psia

- However, upon talking to Thermo Fischer, this gas trap has not been proof/burst tested
  - Thermo Fischer has only done repeat impulse testing (1000x cycles) at each of the MDPs listed above.
- Hydrostat testing can raise the MDP of the degasser from the spec sheet value.
  - This would minimize operational constraints on Gateway flight operations personnel.

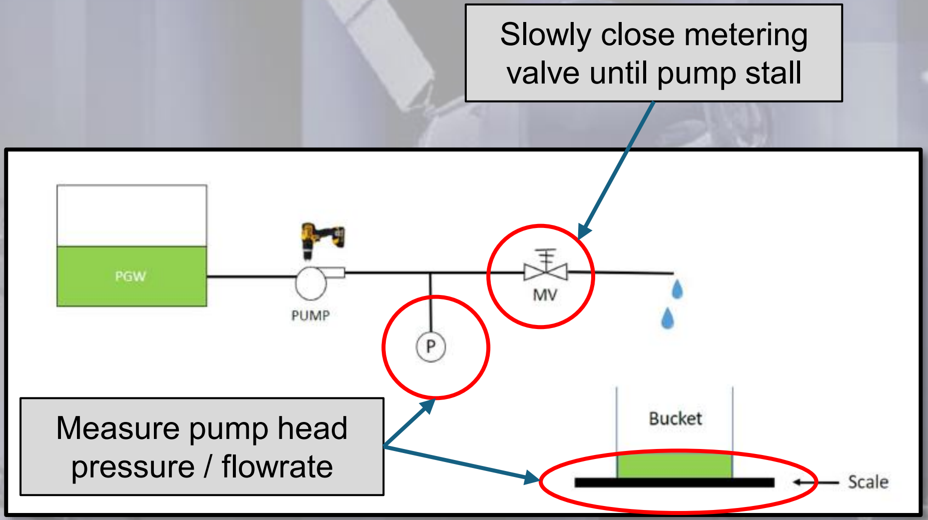
Survived up to ~245psig before showing signs of housing cracking

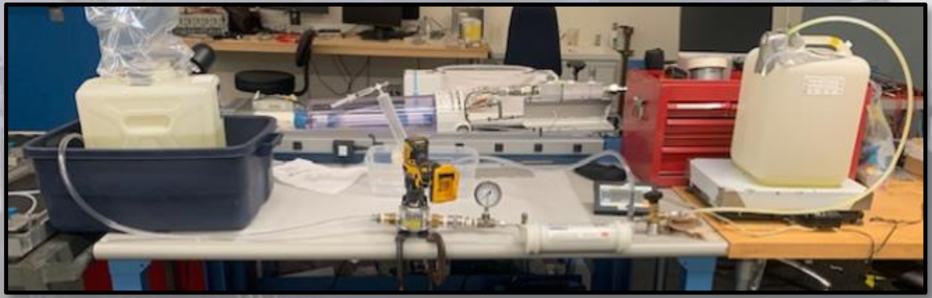
No signs of membrane wet-out

More testing will need to be done with 40/60 PGW at full fluid temperature range.**

CSS Drill Pump Risk Mitigation Testing – Drill Pump Testing

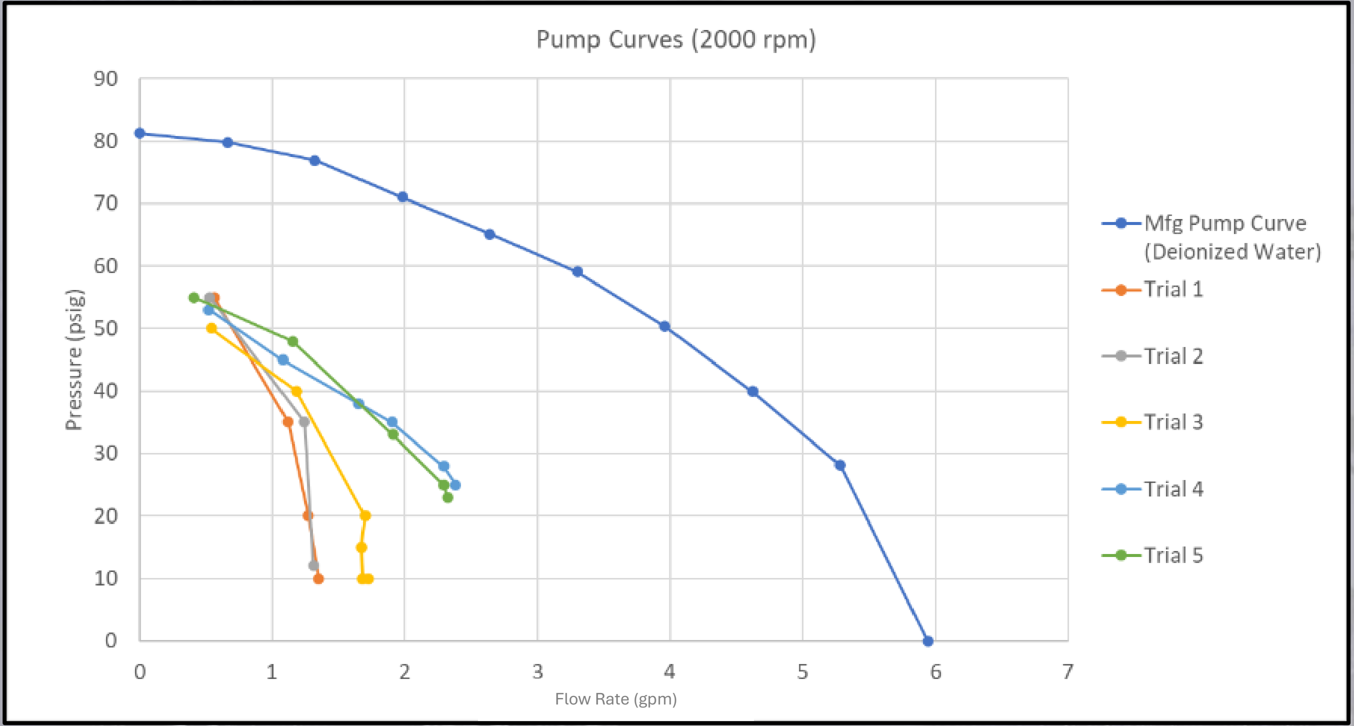
- Drill pump requirements:
  - Minimum Pump Head – 55psia (379.2 kPa)
    - Needs to be able to pump into the Gateway IATCS accumulators at its nominal charge pressure of 55psia (379.2 kPa)
  - Minimum flowrate of 0.53 gpm (2L/min)
    - Need to minimize reliance on active crew time to conduct refill operation.
  - Max touch temperature on drill of 113F (45C)
    - Given by Gateway.
- Testing Goals:
  - Evaluate dead head / flowrate of the drill pump with emulative drill that is in the crew's Intravehicular Activity (IVA) toolkit.
    - Setup test stand to create pump curves (pressure v. flowrate) for drill pump with 40/60 PGW.
  - Conduct battery life test
    - Need to evaluate the max touch temperatures that can be experienced on drill and drill battery.
    - Need to evaluate battery life to cross reference with pump flowrate to determine fill time.





Drill Pump Testing Setup

CSS Drill Pump Risk Mitigation Testing – Drill Pump Testing



Parameter	Value
Battery Life	4.70 minutes
Max Drill Motor Case Temperature	98.6F (37C)
Max Drill Battery Temperature	149F (65C)

- Drill pump flowrate ranged from 0.59gpm to 2.25gpm (2.23L/min to 8.517L/min)
  - 0.59gpm (2.23L/min) at max pump flowrate meets the Gateway requirement
  - Refill time for 1 accumulator is 0.44minutes
  - Refill time for an entire Gateway IATCS loop is 13.53 minutes
- Drill pump max head pressure ranged from 50-55psig (446.06kPa to 480.54 kPa)
  - 50psig = 64.7psia which is higher than the Gateway requirement of 55psia (379.21kPa)
- Drill pump battery time was measured to be 4.70minutes
  - 1 drill pump battery can conduct approximately 10 accumulator refills.
  - Refilling an entire Gateway IATCS loop would take 3 drill pump battery charges

Reference Back to KPPs

	Key Performance Parameter (KPP)	Value	Rationale	Result
1	Degasser Hydrostatic Pressure Maximum	108psia (744 kPa (abs))	1.5 Times the maximum Gateway accumulator set point, 72psia (496 kPa (abs)).	254.7psia (1756.1 kPa (abs)) w/ DI Water (Partial PASS)
2	Degasser Pressure Drop	5 psid (34.47 kPa(d))	No hard requirement set by Gateway, but it is assumed to be a maximum acceptable value when compared to the IATCS pump head.	1.3psid (8.96 kPa(d)) (PASS)
3	Gas Removal Capability	Capable of degassing loop to 0.024in^3 (0.93mL) remaining volume	Assumed to be the smallest bubble diameter that could vapor lock an IATCS pump.	Can degas down to at least 0.024in^3 (0.39mL) (PASS)
4	Drill Pump Minimum Flowrate capability	0.53gpm (2 L/min)	Requirement given from Gateway to decrease reliance on crew time.	0.59gpm (2.23 L/min) (PASS)
5	Drill Pump Head Pressure	55psia (379.2 kPa)	Allows the drill pump to recharge the accumulator to the maximum nominal accumulator set pressure.	64.7psia (446kPa) (PASS)
6	Touch temperature hazards	No unlimited bare skin contact between 32°F (0°C) and 113°F (45°C)	Touch temperature limits given by Gateway Program.	Worst-case touch temperature of 149°F (65°C) (Partial FAIL)

Were allowed to move forward with design with plan to integrate hazard controls in standard operating procedure for crew.

CSS Forward Work

- The Coolant Servicer System was paused in funding in Spring 2026 with the cancellation of the Gateway Space Station
  - However, degassing and refilling of a propylene-glycol based fluid loop applies to any long-term habitat utilizing the same coolant, and the project is currently being shopped to other customers, most notably:

    -Commercial Space Station providers under NASA's Commercial Low Earth Orbit Development (CLDP) Program

    -Moon Base / Multi-Purpose Hab
- CSS ended about halfway to CDR, with immediate future work including:
  - Building a higher-fidelity "EDU Test Stand" that fully emulates the Gateway IATCS coolant loop. This will allow for testing of the EDU for degassing and refill performance in like-conditions and provide mass data capture on performance bounds.
  - Performance testing on full EDU prototype to verify the design meets requirements and bound operational constraints for Gateway FOD (time to degas/refill, etc.).
  - Conducting materials compatibility testing on wetted materials of concern with 40/60 Propylene-Glycol Water (GWaTR bag, Drill Pump Impellers, Degasser Cartridge).
  - Development of controlled GSE for qualification testing per the CSS team's verification plan.

Thank you!

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  - Rubik Sheth
  - Paul Rathbun
  - Teresa Schurtz
  - Frederick Smith
  - David Westheimer
  - Marisa Markley

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References:

[1]
J.T. Humphrey, Laura N. Supra, and Michael B. Faust, "A Thermal Control System Dual-Membrane Gas Trap for the International Space Station," in *27th International Conference on Environmental Systems*, Lake Tahoe, Nevada, SAE 97-69273, 1997.
[2]
T.O. Leimkuehler, C. Spelbring, D.R. Reeves, and J.M. Holt, “Development of the Next Generation Gas Trap for the Space Station Internal Thermal Control System,” in *33rd International Conference on Environmental Systems*, Seattle, Washington, ICES-2003-01-2566, 2003.
[3]
J.H. Miernik, F.H. Schubert, “Fluid Systems Servicing and Leak Check for the International Space Station,” in *28th International Conference on Environmental Systems*, Danvers, Massachusetts, ICES 2000-01-2310.