JSC/EC5 U.S. Spacesuit Knowledge Capture (KC) Series Synopsis

All KC events will be approved for public using NASA Form 1676.

This synopsis provides information about the Knowledge Capture event below.

Topic: Design and Testing of the Sheet and Hollow Fiber Spacesuit Water Membrane Evaporators

Date: September 30, 2010 **Time:** unknown **Location:** JSC/B5S/R3204

DAA 1676 Form #: 29691

A PDF of the presentation is also attached to the DAA 1676 and this is a link to all lecture material and video: \\js-ea-fs-01\pd01\EC\Knowledge-Capture\FY10 Knowledge Capture\20100930_Bue-Vogel_SWMEs\For 1676 Review & Public Release

*A copy of the video will be provided to NASA Center for AeroSpace Information (CASI) via the Agency's Large File Transfer (LFT), or by DVD using the USPS when the DAA 1676 review is complete.

Assessment of Export Control Applicability:

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* This PDF is also attached to this 1676 and will be used for distribution.

For 1676 review use_Synopsis_Bue & Vogel_Water Membrane Evaporators_9-30-2010.pdf

Presenters: Grant Bue and Matthew Vogel

Synopsis: Grant Bue and Matthew Vogel presented the two types of Spacesuit Water Membrane Evaporators (SWME) that were developed based on hydrophobic microporous membranes. One type, the Sheet Membrane (SaM) SWME, is composed of six concentric Teflon sheet membranes fixed on cylindrical-supporting screens to form three concentric annular water channels. Those water channels are surrounded by vacuum passages to draw off the water vapor that passes through the membrane. The other type, the Hollow Fiber (HoFi) SWME, is composed of more than 14,000 tubes. Water flows through the tubes and water vapor passes through the tube wall to the shell side that vents to the vacuum of space. Both SWME types have undergone testing to baseline the performance at predicted operating temperatures and flow rates; the units also have been subjected to contamination testing and other conditions to test resiliency.

Biographies: Grant Bue has a bachelor of arts in biology from Harvard University and two degrees from the University of Texas at Austin: a bachelor of science in mechanical engineering and a master of science in biomedical engineering. He supported the CTSD at JSC for 15 years as a Lockheed Martin contractor and for 8 years as a civil servant in the thermal management of humans working in and around spacecraft.

Matthew Vogel has a bachelor of science in aerospace engineering from Texas A&M University and a master of science in mechanical engineering from the University of Houston. He was a cooperative education student at Rockwell International in the Transportation Systems Division and later worked on the space station contract at McDonnell Douglas. He began working for Jacobs Technology in 1994, and has worked as a thermal designer and analyst at JSC for more than 18 years.

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Hollow Fiber Spacesuit Water Membrane Evaporator Development and Testing for Advanced Spacesuits

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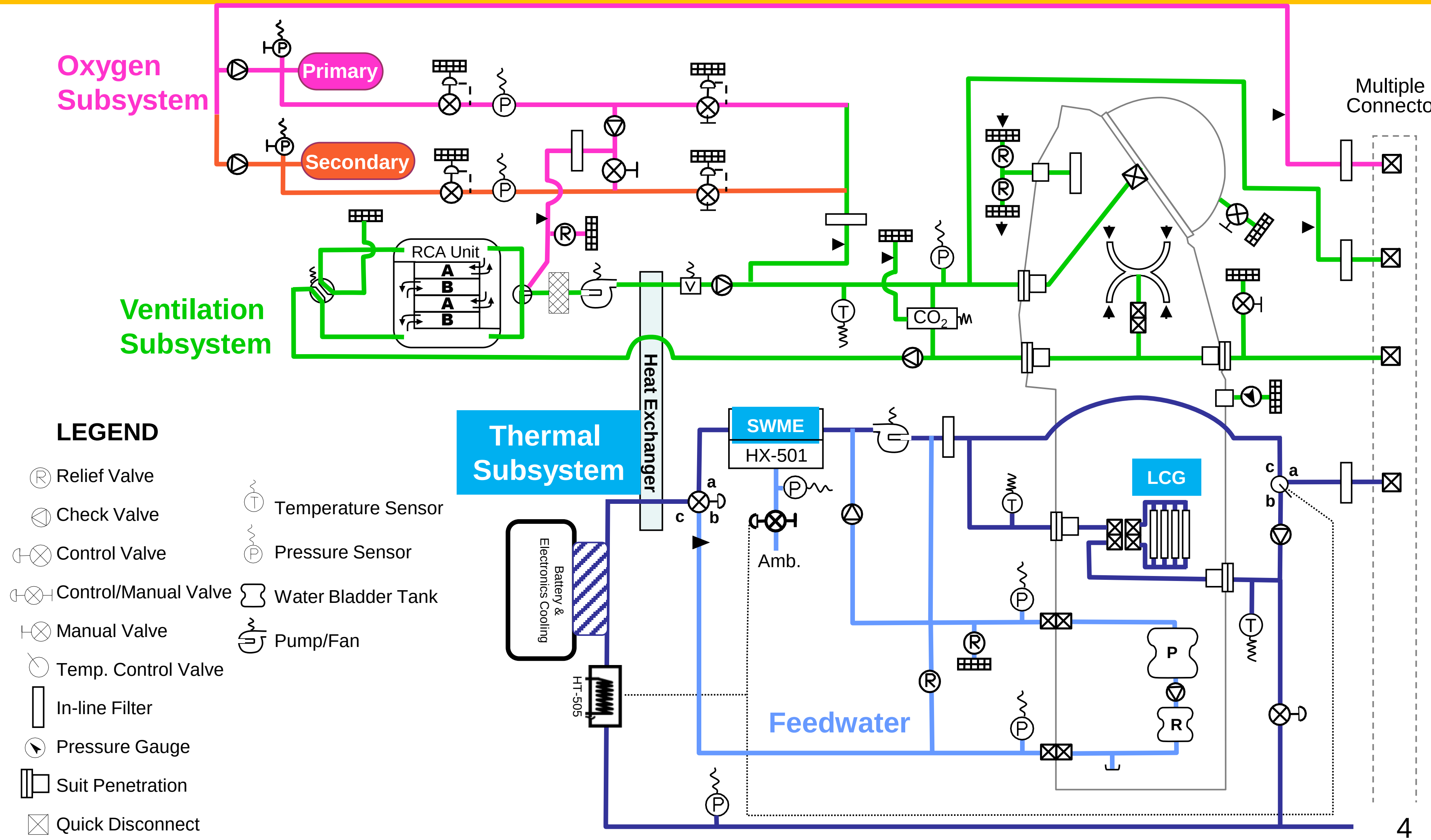
Overview

- Background
- Requirements
- Test Regime
- Sheet Membrane SWME Design
- Hollow Fiber SWME Design
- Test Setup
- Test Results
- NASA Downselect and Next Prototype

Background

- Rejects spacesuit crew, avionics, & environmental heat
  - By evaporating water as compared to sublimation
- SWME technology development pursued due to potential to increase spacesuit thermal control robustness & capability
  - Operate above water triple point pressure (Mars)
  - Eliminates separate feedwater system
  - Provides degassing of water loop
  - Insensitivity to contaminants in water

Background



Oxygen Subsystem
Primary
Secondary
Multiple Connector
Ventilation Subsystem
RCA Unit
A
B
A
B
CO2
Heat Exchanger
Thermal Subsystem
SWME
HX-501
Amb.
LCG
Battery & Electronics Cooling
HT-505
Feedwater
P
R
a
b
c
LEGEND
Relief Valve
Check Valve
Control Valve
Control/Manual Valve
Manual Valve
Temp. Control Valve
In-line Filter
Pressure Gauge
Suit Penetration
Quick Disconnect
Temperature Sensor
Pressure Sensor
Water Bladder Tank
Pump/Fan

Background

- Independent, parallel SWME development efforts led to two different SWME designs
  - Designs differences driven by type of membrane used
    - Both membranes are hydrophobic, porous membranes
  - Sheet Membrane (SaM) SWME
    - Gasket SaM SWME
    - O-ring SaM SWME
  - Hollow Fiber (HoFi) SWME
    - HoFi #1 without spacers
    - HoFi #2 with spacers

Requirements

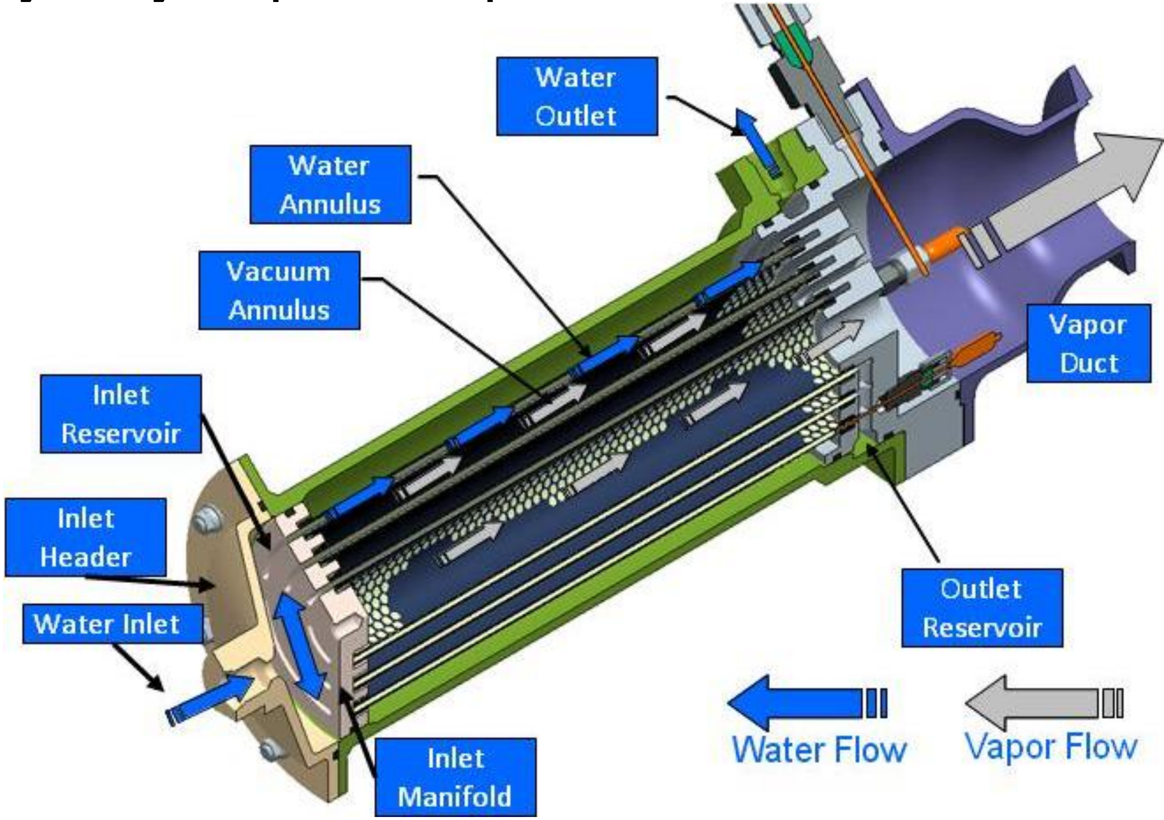
- SWME Requirements for Advanced Spacesuit imposed on both designs
  - Maximum heat load of 807 watts (2754 Btu/hr) at 10 °C (50 °F) water outlet.
  - Minimum heat load of 81 watts (276 Btu/hr) at 24 °C (75 °F) water outlet.
  - Capability to turn off SWME heat rejection (0 watts) at any time
  - Water Flowrate into SWME: 91kg/hr (200lbm/hr)
  - Internal water pressures of 30 - 69 kPa (4.2 - 10 psid) in external Vacuum EVA environment or Mars environment. 6 mbar to10 mbar (0.46 torr to 0.76 torr) CO_2
  - SWME Useful Life: 100 EVA's, 8 hours each
  - Use potable water from the Water Processor Assembly, with biocide
  - Replaceable between operations
  - Volume: <6.89 liters (< 421 in^3)
  - Mass: <5.44 kg (<12.0 lbm)

Test Regime

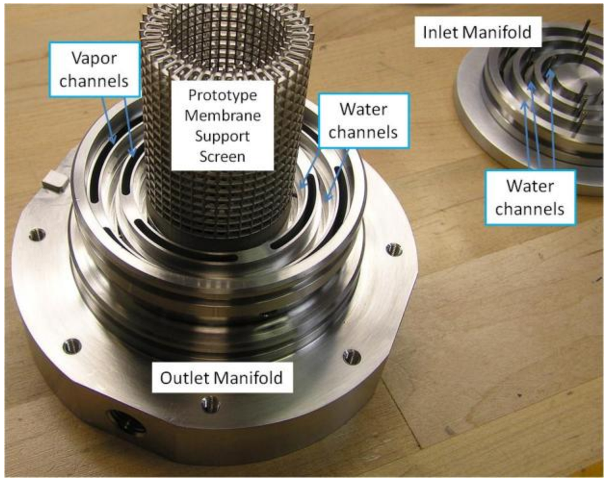
- Testing conducted to characterize performance, test robustness and aid in prototype downselect
  - Performance tests: Heat rejection as a function of water vapor backpressure, coolant inlet temperature and coolant pressure
  - Contamination tests: Degradation of heat rejection as a function of water purity spanning contaminate accumulation over 100 EVA s of 8 hours duration
  - Mars tests: Heat rejection performance at external pressures at or above Mars atmospheric pressure, both with and without sweep gas
  - Freeze tests: Integrity of prototypes in multiple freeze/thaw cycles and recovery of baseline performance
  - Bubble tests: Performance response to injection of gas bubbles into coolant loop
  - Cut fiber tests: Performance impact of cutting two fibers (HoFi only)

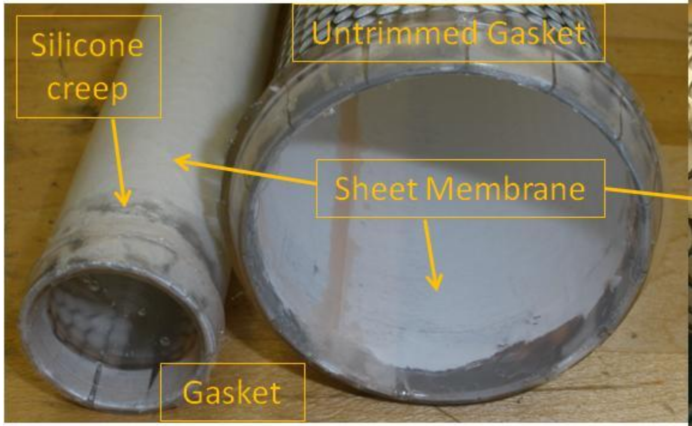
SaM SWME Test Articles

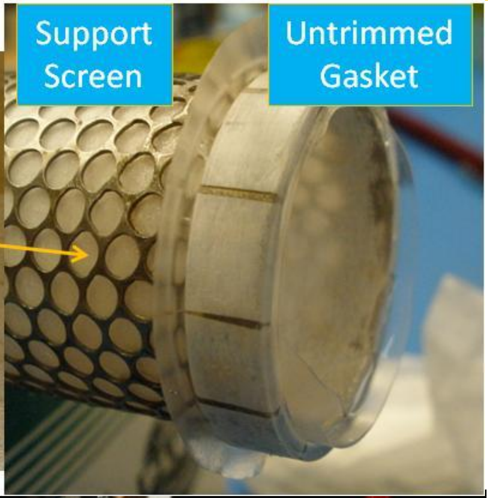
- Annular design formed by 6 hydrophobic, porous Teflon sheet membranes
  - 3 water channels
  - 4 vapor channels
  - 200 mm length
  - 57 mm outermost sheet diameter
  - $0.155 m^2$ membrane surface area
  - GE Energy product
    - 0.1 µm average pore size

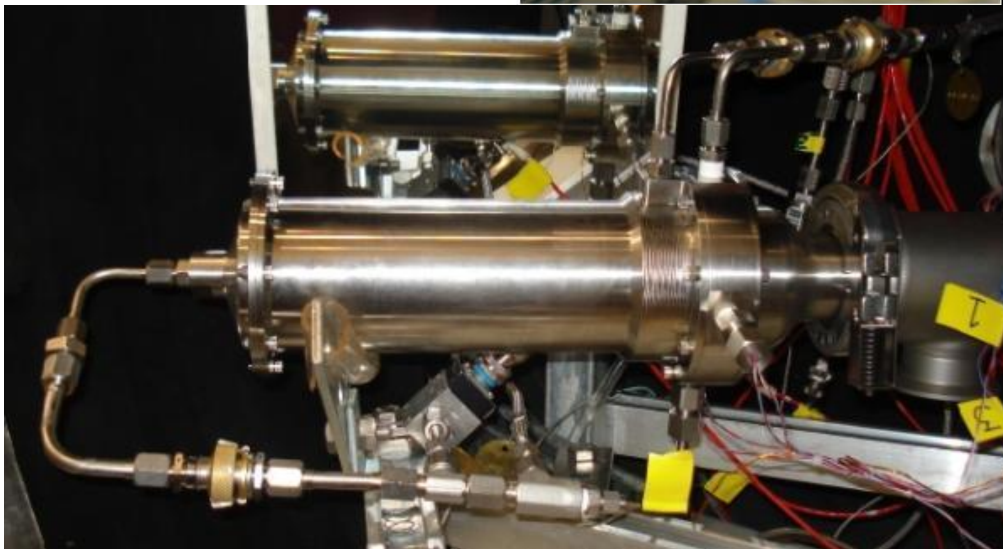


Gasket SaM SWME Test Article

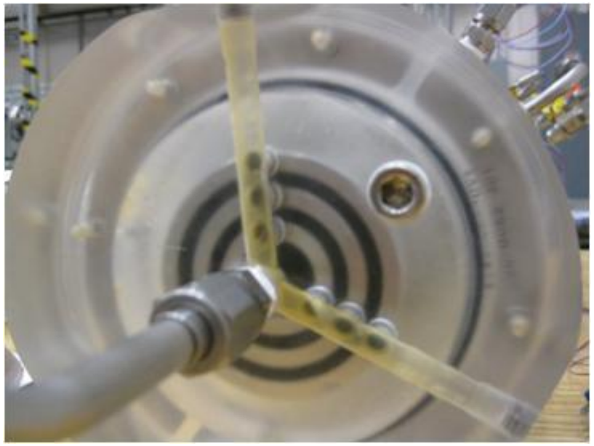


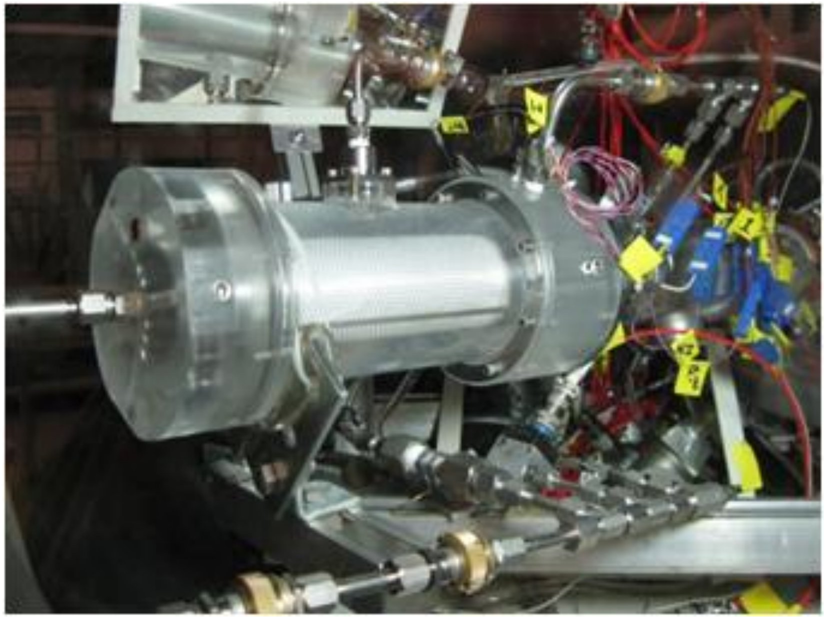


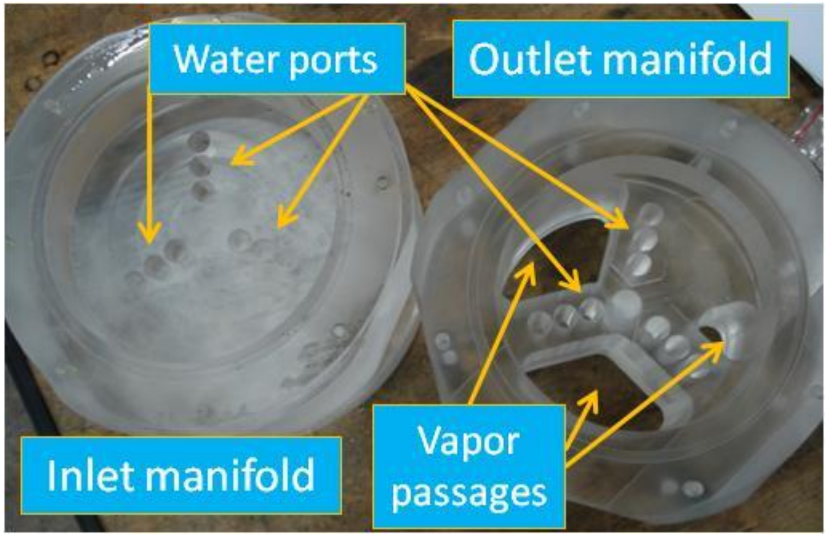




O-ring SaM SWME Test Article



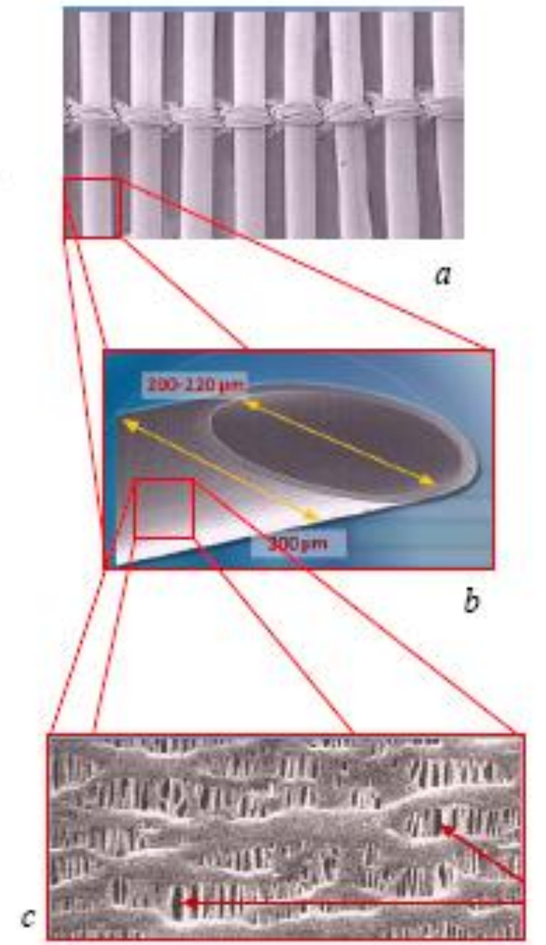




HoFi SWME Design

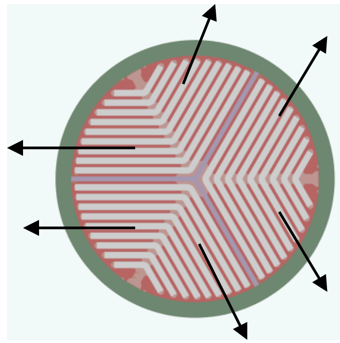
Fiber Characteristics

- Microporous hollow fiber membrane was obtained from COTS hardware (Membrana Celgard X50-215
  a. Fibers arranged linearly in a fabric with 20 fibers per cm
  b. Polypropylene HoFi, 220-µm internal diameter, 40-µm wall thickness, 15.5 kg/cm^2 (400 psi) burst strength
  c. 40% nominal porosity, 0.04x0.10-µm pore size

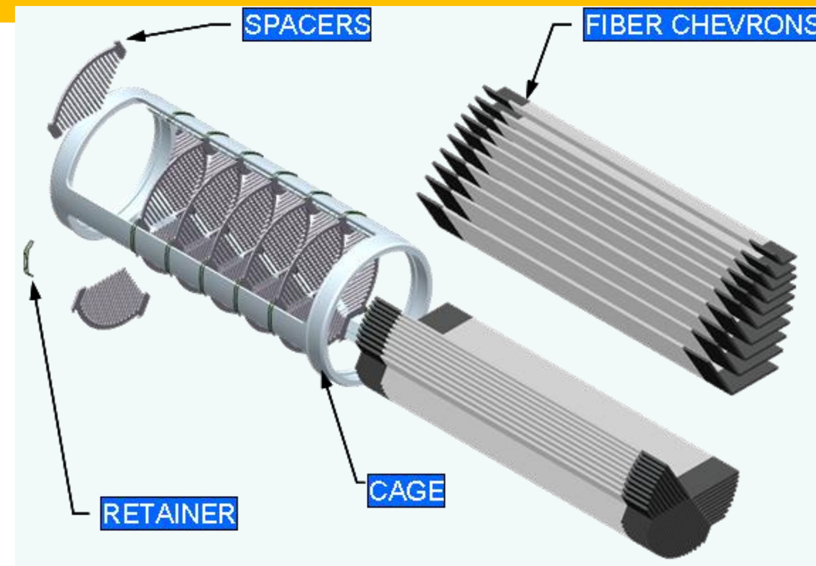


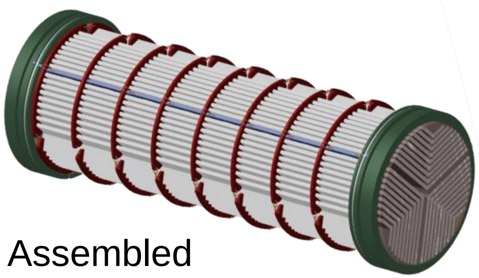
HoFi SWME Design (continued)

Chevron fiber layer stack

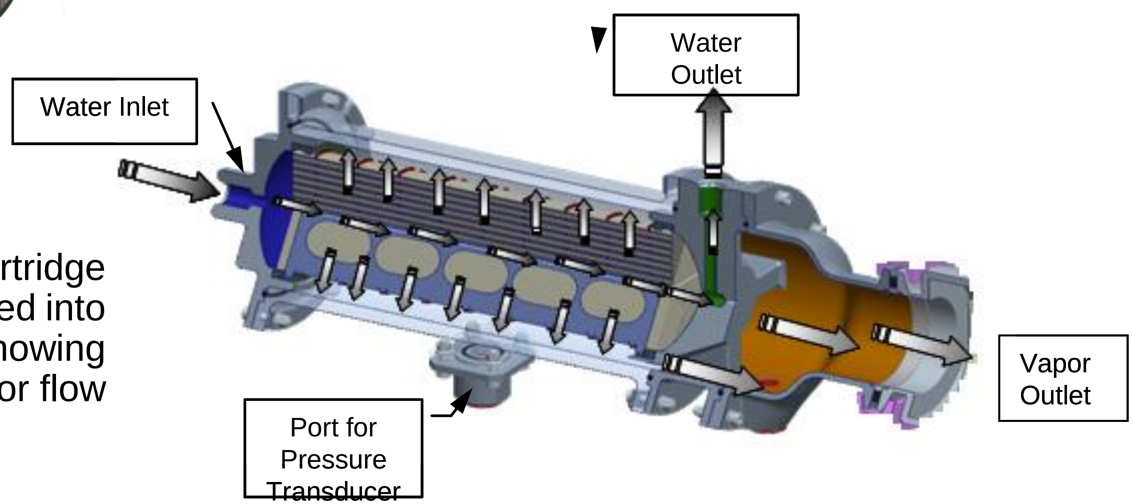


End view of cartridge assembly showing vapor flow directions.



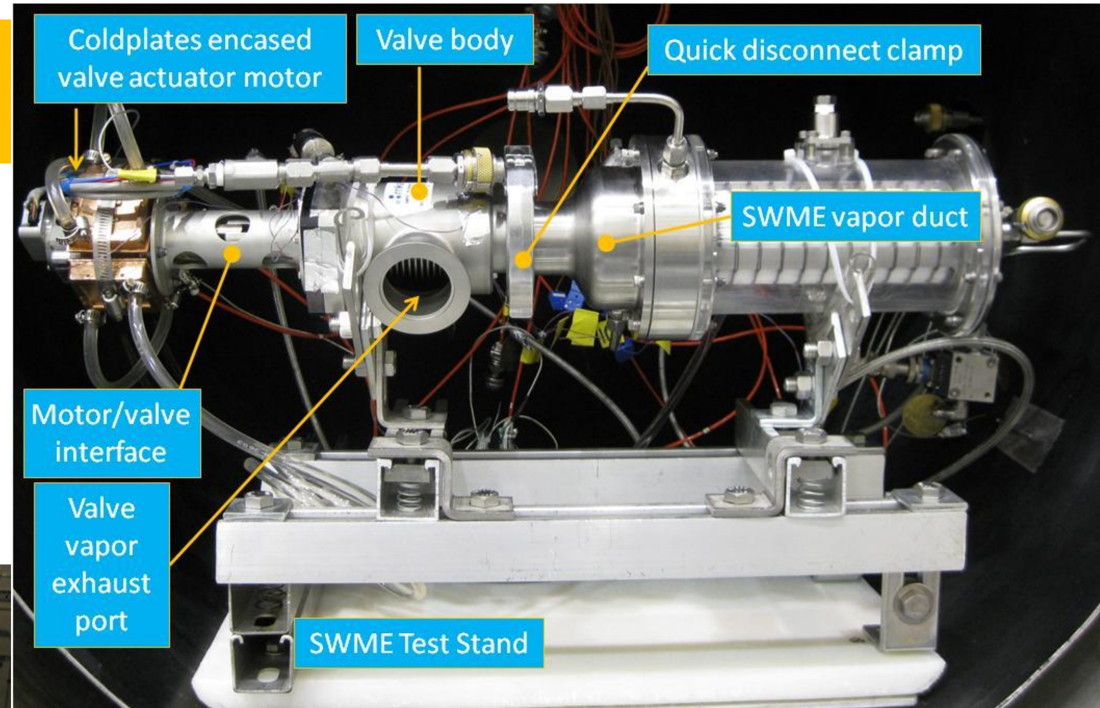


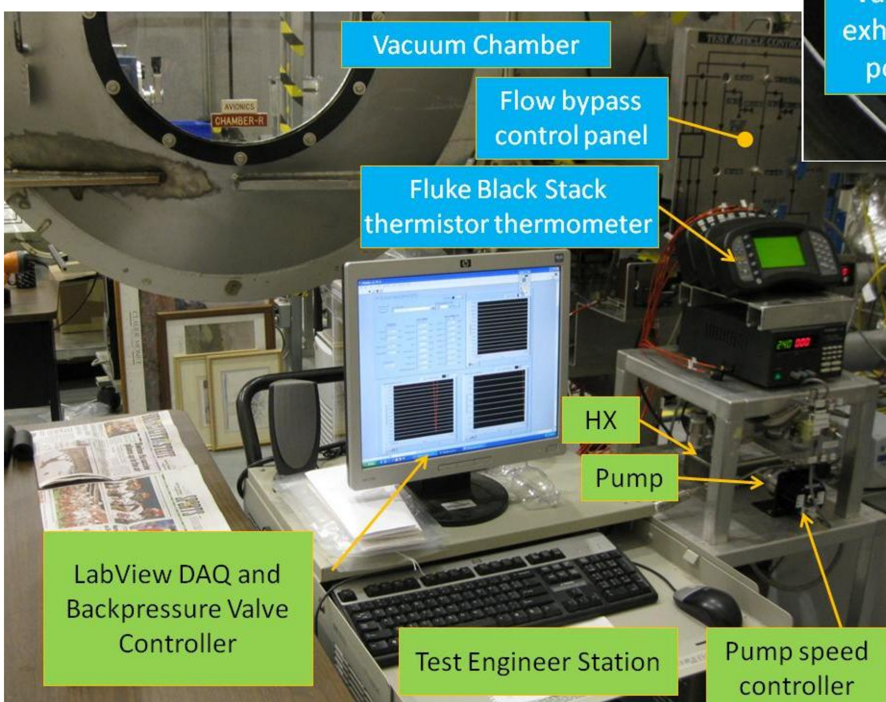
Assembled cartridge
~14300 fibers



Potted cartridge assembled into housing showing water and vapor flow

Test Setup





$\dot{m}$ = Flow Meter

P_i = Inlet Pressure

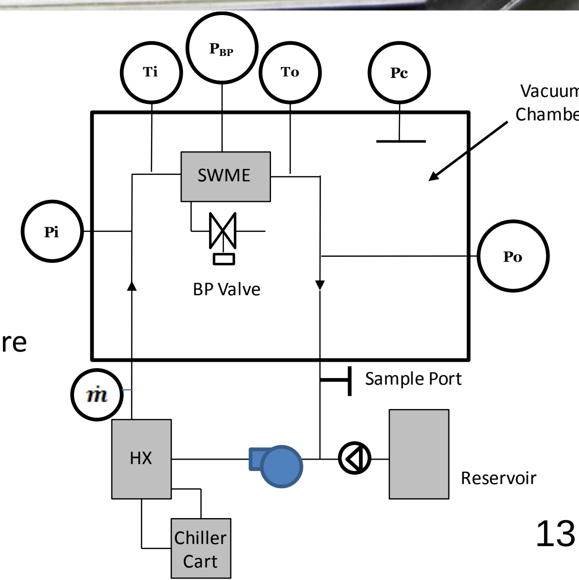
T_i = Inlet Temperature

P_{BP} = SWME Back Pressure

T_o = Outlet Temperature

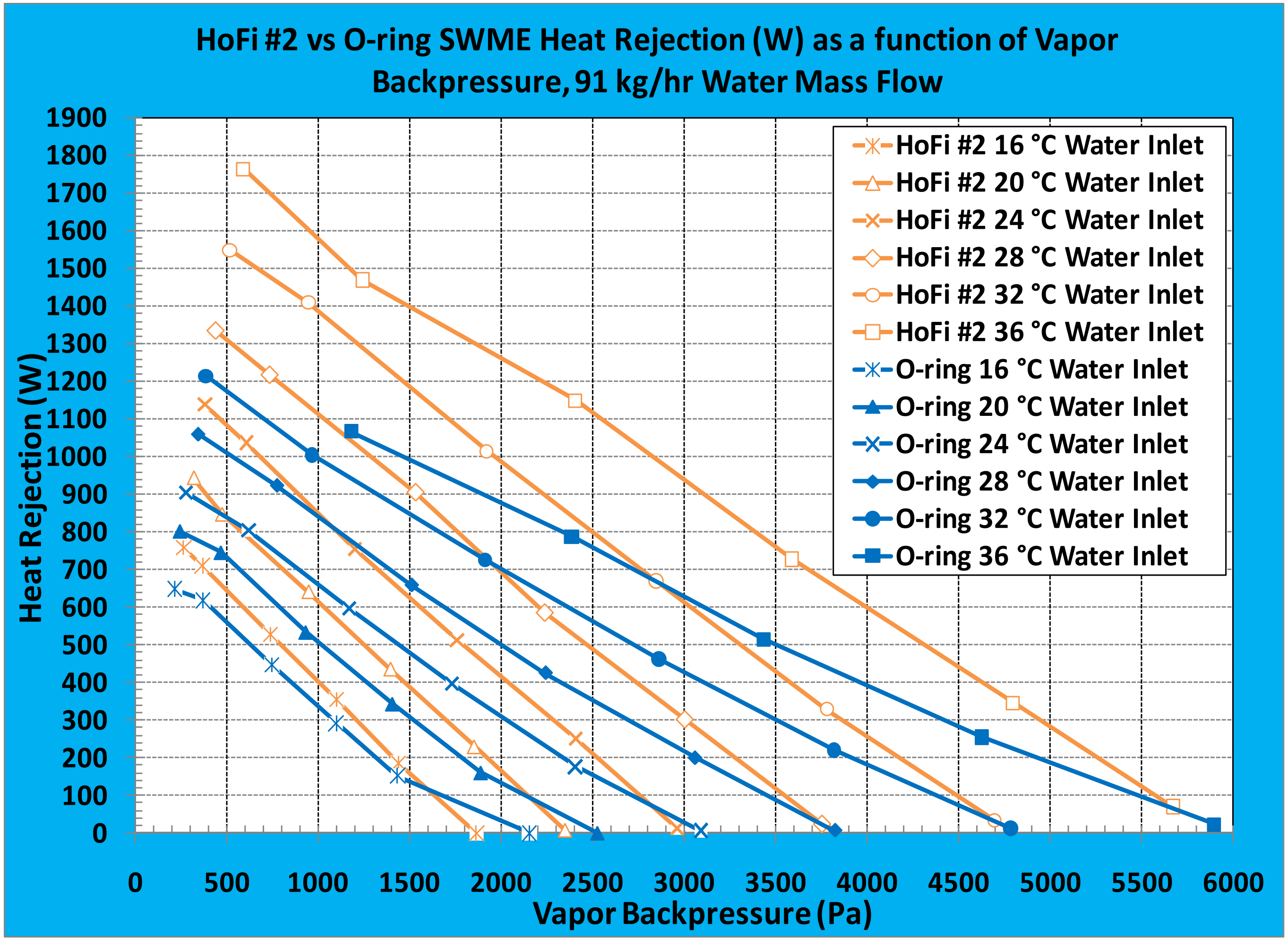
P_o = Outlet Pressure

P_c = Chamber Pressure



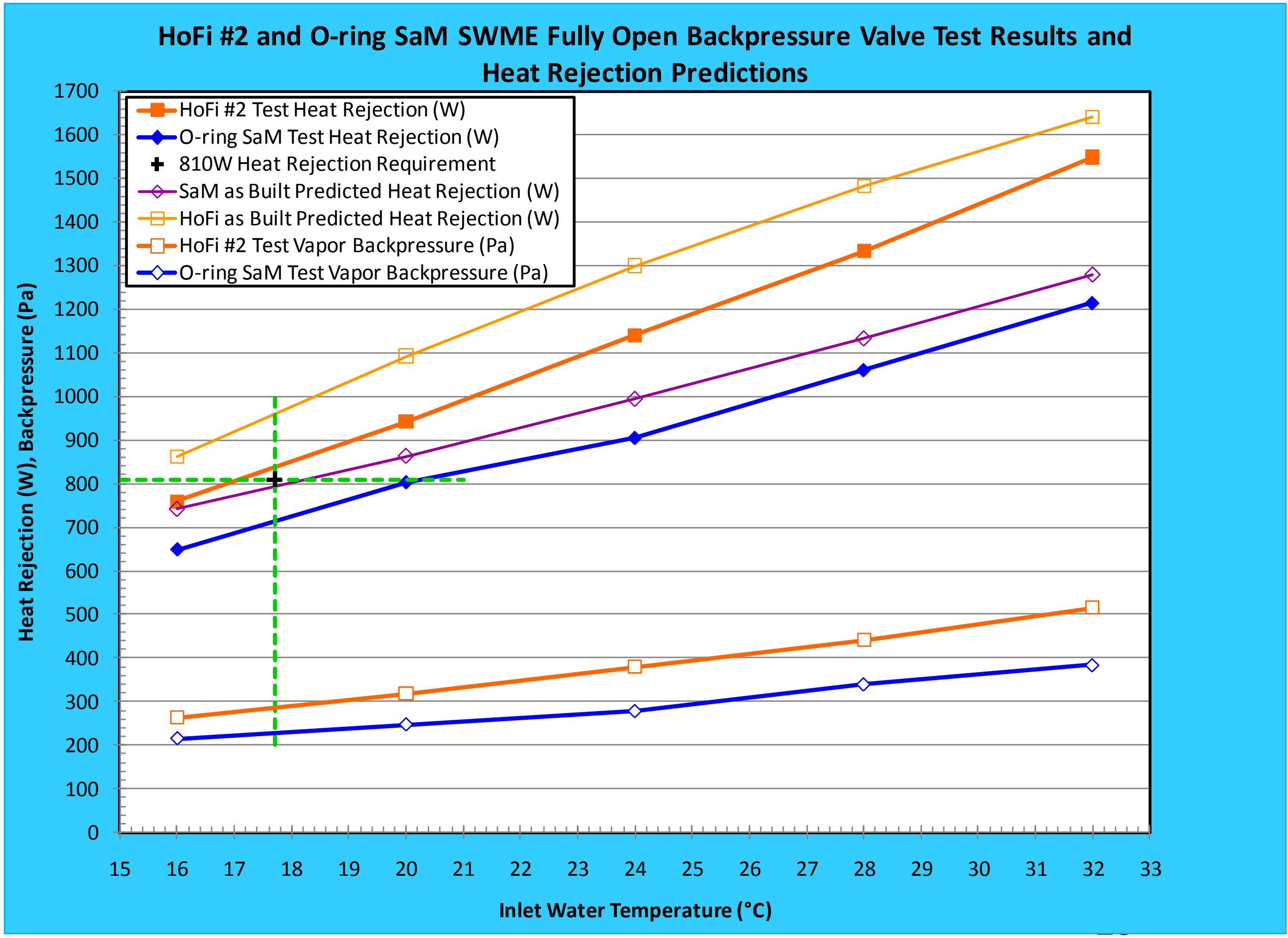
Performance Test Results: HoFi vs. Sam

- Performance mapping test results – HoFi outperformed SaM at all test points



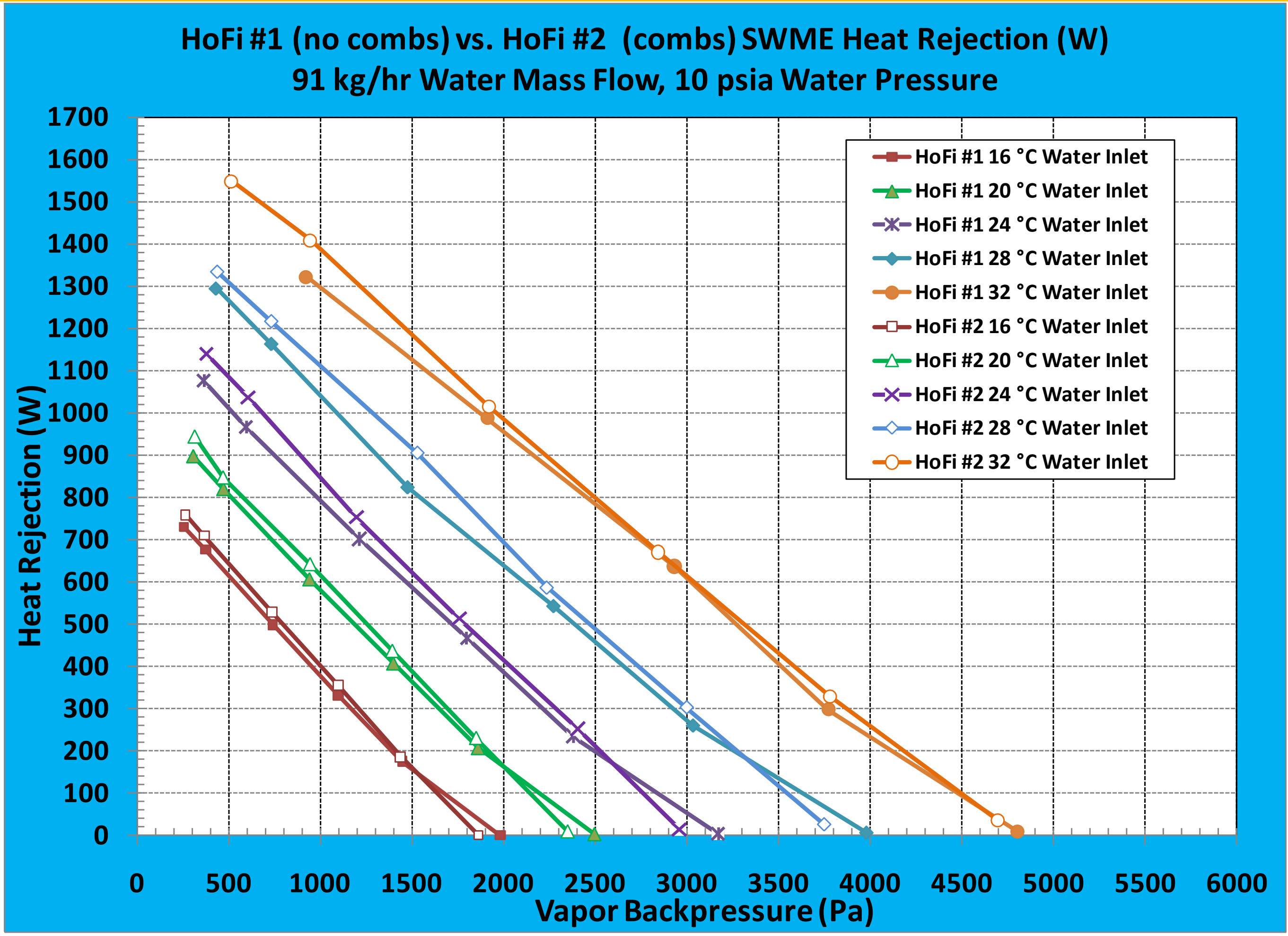
Performance Test Results: HoFi vs. Sam

- At fully open valve position and specification coolant inlet temperature of 17.7 °C, HoFi rejects 15% more heat than SaM
- At fully open valve position, performance advantage of HoFi ranged from 13% at 16 °C to 27% at 32 °C
  - Total pore area differential is key to enhanced performance of HoFi, 0.65 m^2 vs. 0.11 m^2
- Math model predictions for both SWME types were optimistic



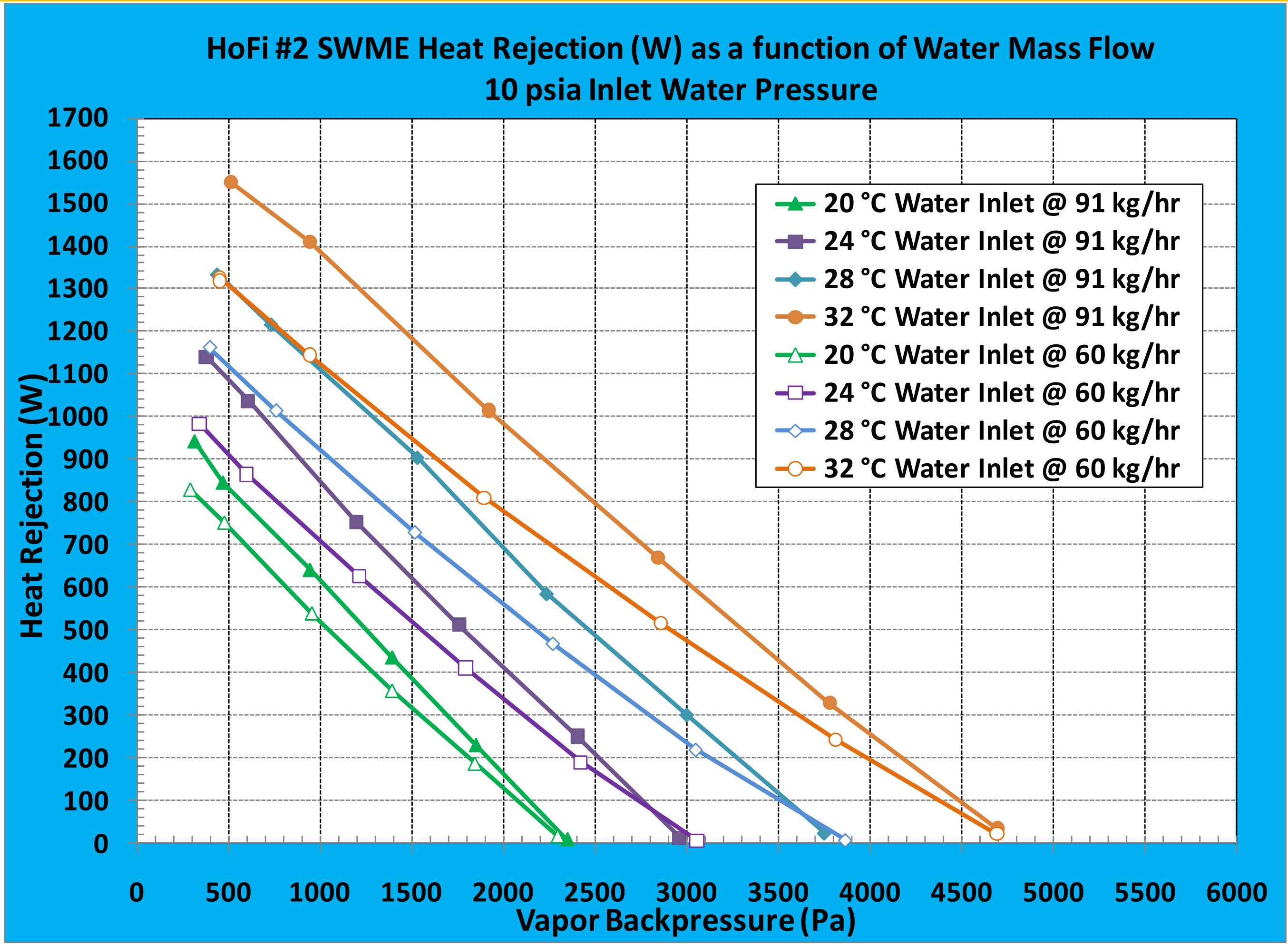
Performance Test Results: HoFi with and without comb spacers

- Comb spacers only improved performance at fully open valve position by 3-4%
- Previous work showed tightly packed configurations are inefficient
- Performance improvement is due more to reduced tube density than spaces between chevron stacks



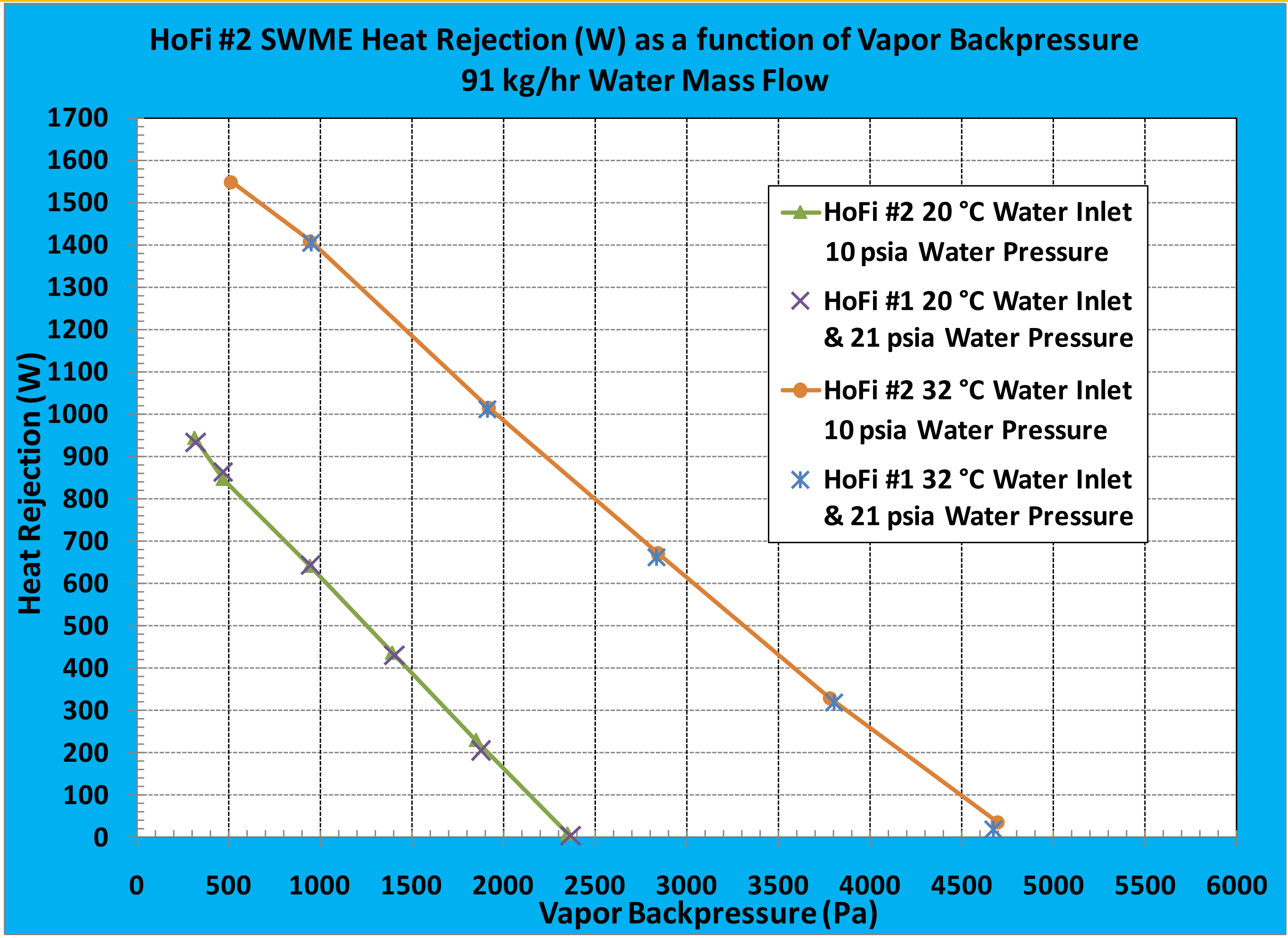
Performance Test Results: 91 kg/hr vs. 60 kg/hr Coolant Flow

- Increasing flow rate from 60 kg/hr to 91 kg/hr improved heat rejection at the fully open valve position by 14% to 17%
- Improvement is expected because higher flowrate yields a higher mean temperature and therefore a higher driving pressure at the water/pore interface



Performance Test Results: 10 psia vs. 21 psia Inlet Pressure

- Nominal pressure at coolant inlet, 10 psia compared to max pressure of contingency scenario of 21 psia
  - No significant heat rejection performance difference between coolant pressures cases across range of backpressures
  - Tube and pore geometry is apparently not changed significantly by the increase in coolant pressure



Contamination testing results

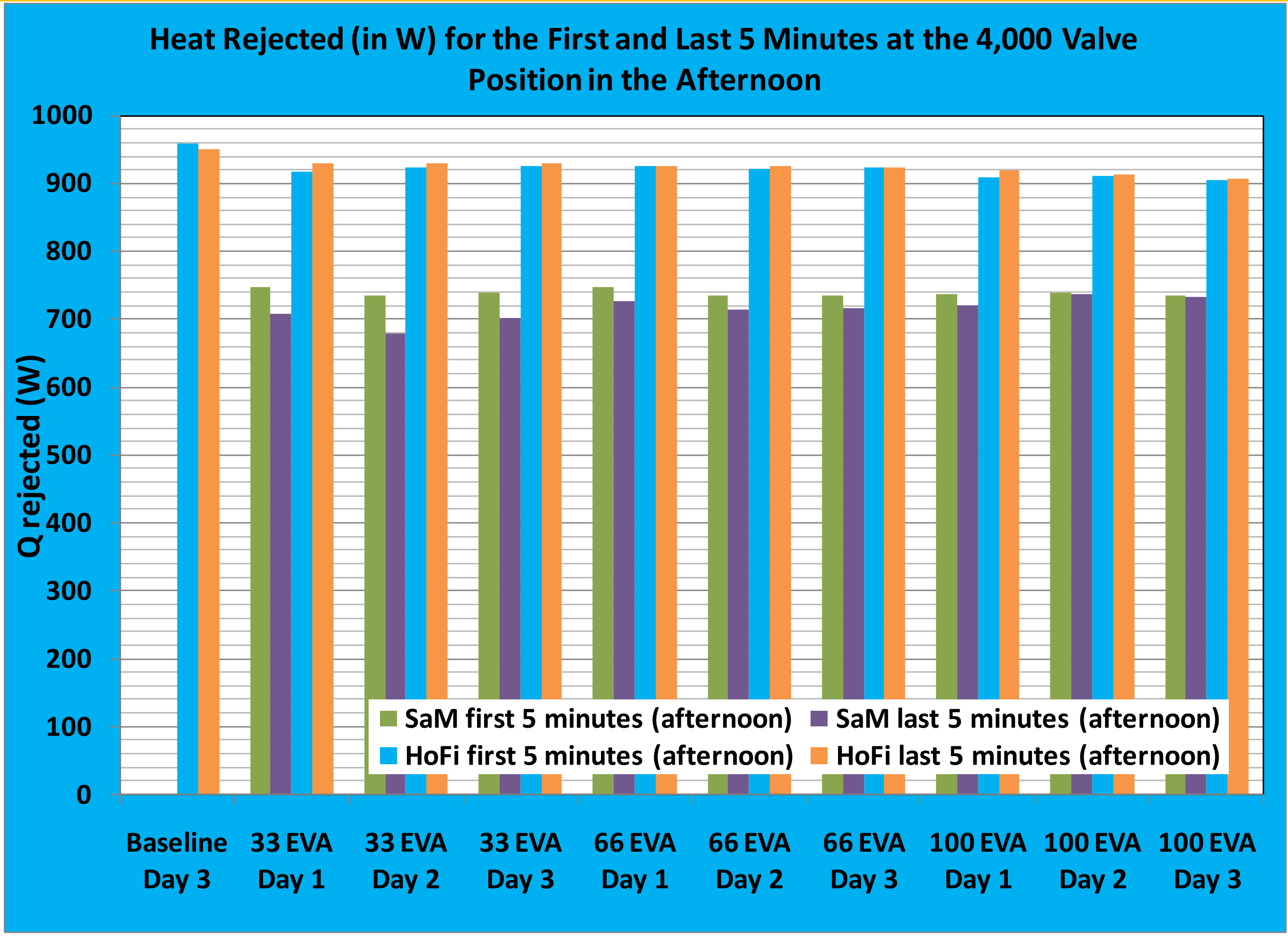
- Contaminant constituents
  - Assumes no water loop flush over 100 EVAs
  - 12 days of testing
    - 3 days at each contamination level

	Units of Measure	CxP Maximum Contaminant Level (MCL)	CxP MCL Source	Baseline Water Quality (0 Hours)	33 EVAs (264 Hours)	66 EVAs (528 Hours)	100 EVAs (800 Hours)
INORGANIC CONSTITUENTS							
Ammonia	mg/L	1	SWEG	0.1	1.9216	3.7432	5.62
Barium	mg/L	10	SWEG	0.1	1.9216	3.7432	5.62
Cadmium	mg/L			0.005	0.09476	0.18452	0.277
Calcium	mg/L			1	19.216	37.432	56.2
Chlorine (Total)	mg/L			5	94.76	184.52	277
Chromium	mg/L			0.05	0.9476	1.8452	2.77
Copper	mg/L	1	SWEG	0.5	9.476	18.452	27.7
Iron	mg/L	0.3	SWEG	0.2	2.84	5.48	8.2
Lead	mg/L			0.05	0.9476	1.8452	2.77
Magnesium	mg/L			1	19.216	37.432	56.2
Manganese	mg/L	0.3	SWEG	0.05	0.9476	1.8452	2.77
Mercury	mg/L			0.002	0.03896	0.07592	0.114
Nickel	mg/L	0.3	SWEG	0.05	0.9476	1.8452	2.77
Nitrate (NO3-N)	mg/L			1	19.216	37.432	56.2
Potassium	mg/L	340	SWEG	5	94.76	184.52	277
Selenium	mg/L			0.01	0.19216	0.37432	0.562
Sulfate	mg/L	250	SWEG	5	94.76	184.52	277
Sulfide	mg/L			0.05	0.9476	1.8452	2.77
Zinc	mg/L	2	SWEG	0.5	9.476	18.452	27.7
ORGANIC CONSTITUENTS							
Total Acids	mg/L			0.5	9.476	18.452	27.7
Total Alcohols	mg/L			0.5	9.476	18.452	27.7
Total Organic Carbon	mg/L	3	SWEG	0.3	5.844	11.388	17.1
MICROBIAL BACTERIA: TOTAL COUNT							
Bacteria	CFU/mL			1	TBD	TBD	TBD
Fungi	CFU/mL			1	TBD	TBD	TBD

* EVA concentrations calculated based on 10L initial volume
** 1 EVA is equivalent to 8 hours

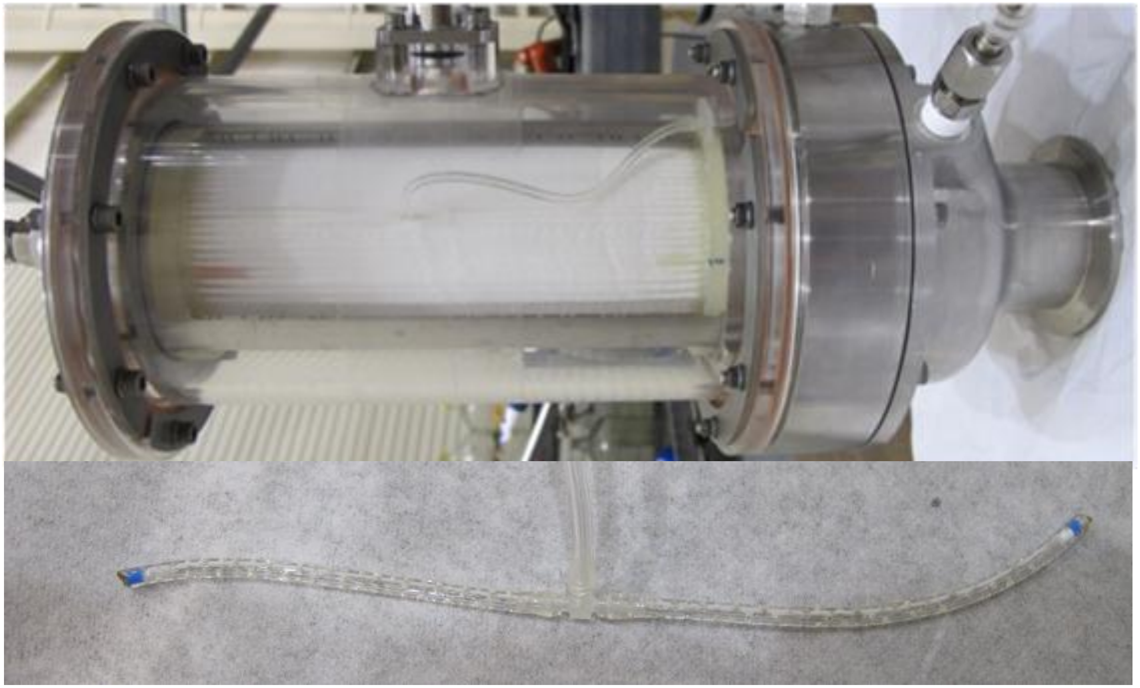
Contamination testing results (continued)

- Both units are contamination insensitive for water constituent concentrations that span the possible range
- Some performance degradation apparent after Baseline runs in HoFi system, but thereafter performance levels are essentially constant
- SaM system showed little to no degradation throughout test



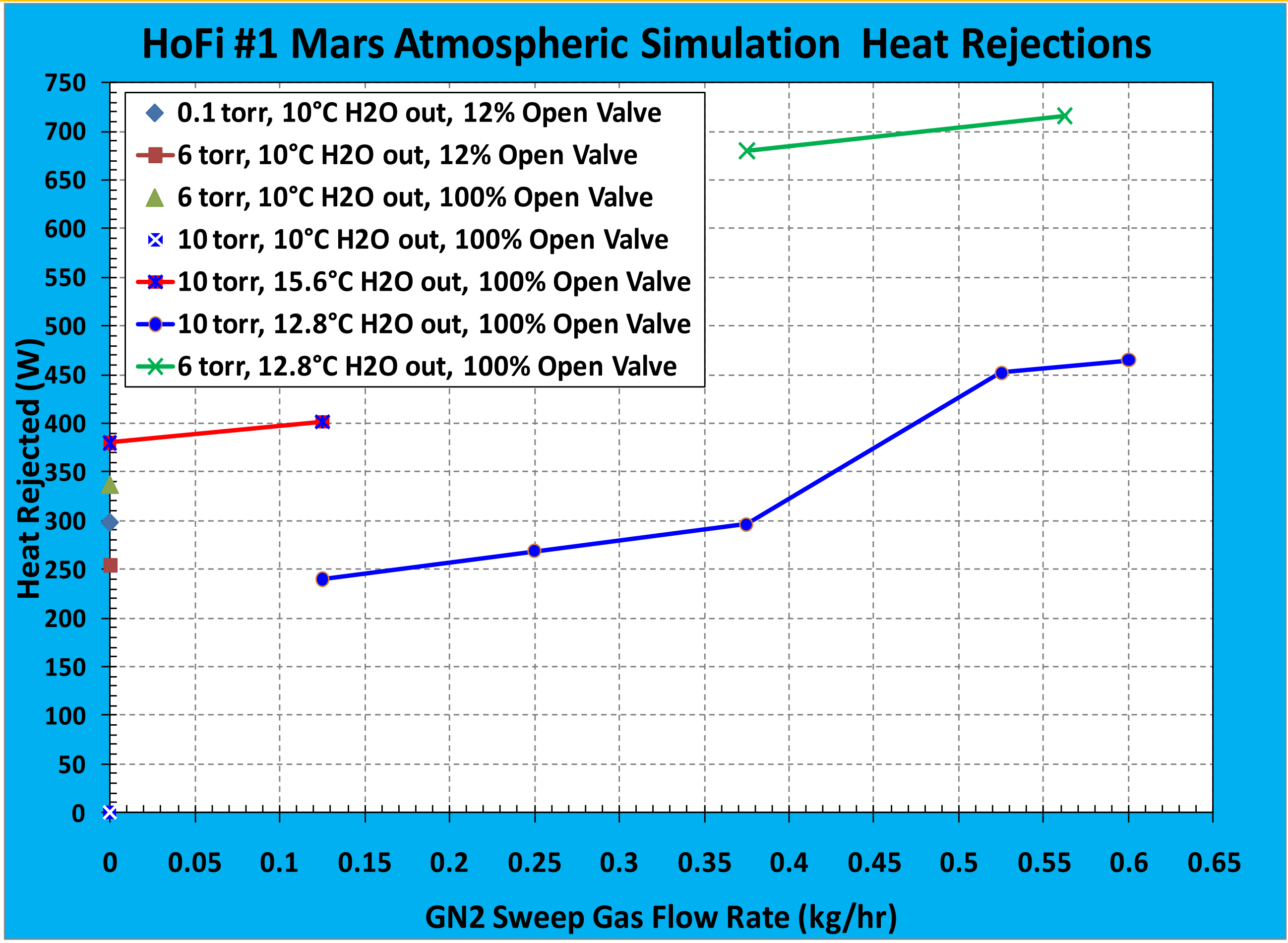
Mars Test HoFi Setup

- Perforated tube was placed into triangular space at axial center between innermost chevrons of the three sectors
- Tube was used to distribute nitrogen sweep gas for high performance heat rejection
- Gaseous nitrogen was used to elevate chamber pressure to Mars atmospheric pressure (6 torr) and to a higher level level (10 torr)
  - Mars atmosphere varies from about 6 mbar to10 mbar (0.46 torr to 0.76 torr)



Mars Test Results

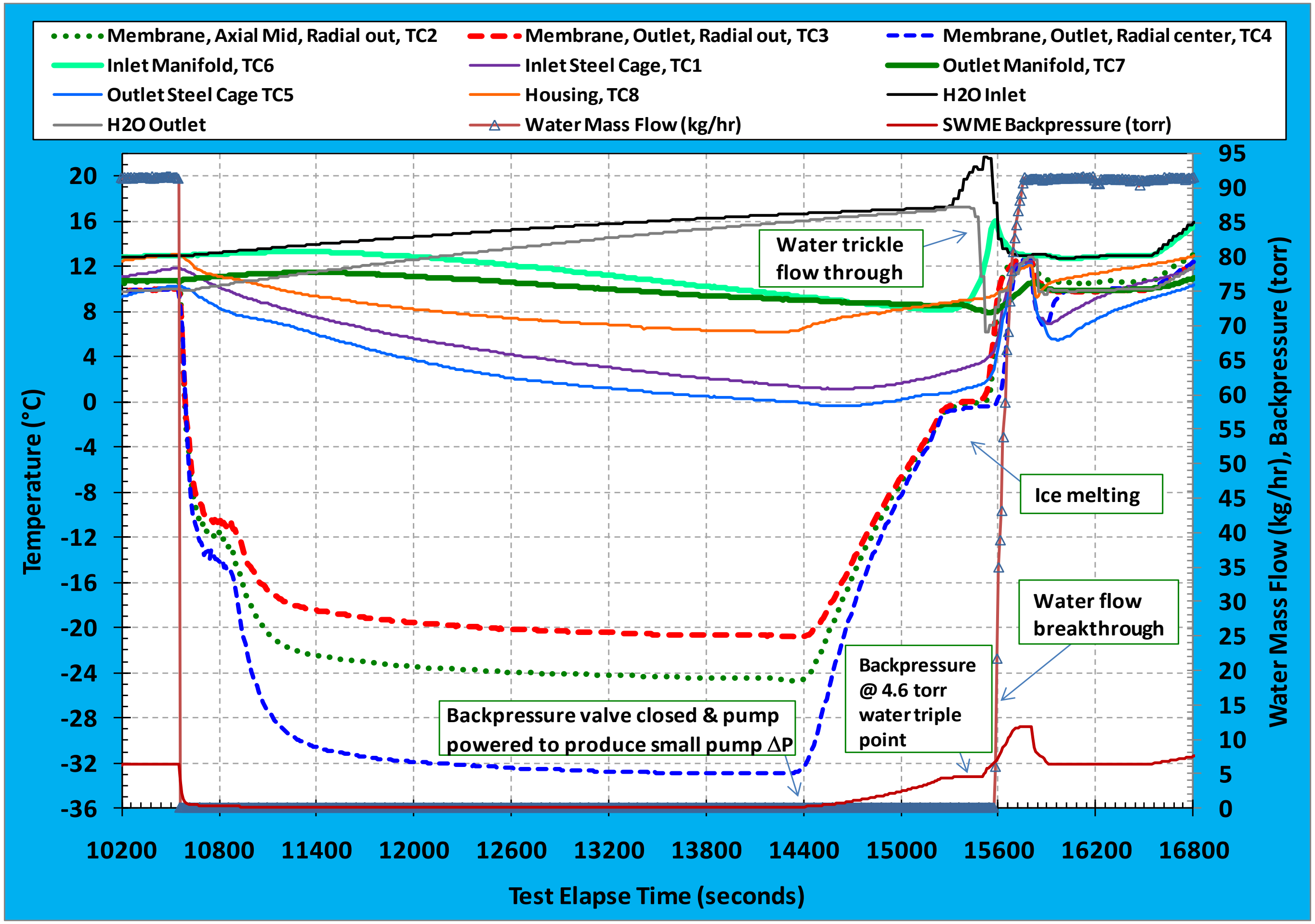
- 380 W rejected against pressure higher than Mars pressure without sweep gas
  - This is equivalent to nominal EMU heat load
- At sweep gas flow of 0.56 kg/hr, 716 W were rejected against Mars pressure
- HoFi SWME significantly outperform SaM SWME in this test due to differential in total pore area



Freeze Test Results

- Water flow was stopped with the backpressure valve fully open allowing water in membranes between the inlet and outlet manifolds to completely freeze
- Both HoFi and SaM systems repeatedly endured multiple freeze/thaw cycles with full restoration of performance

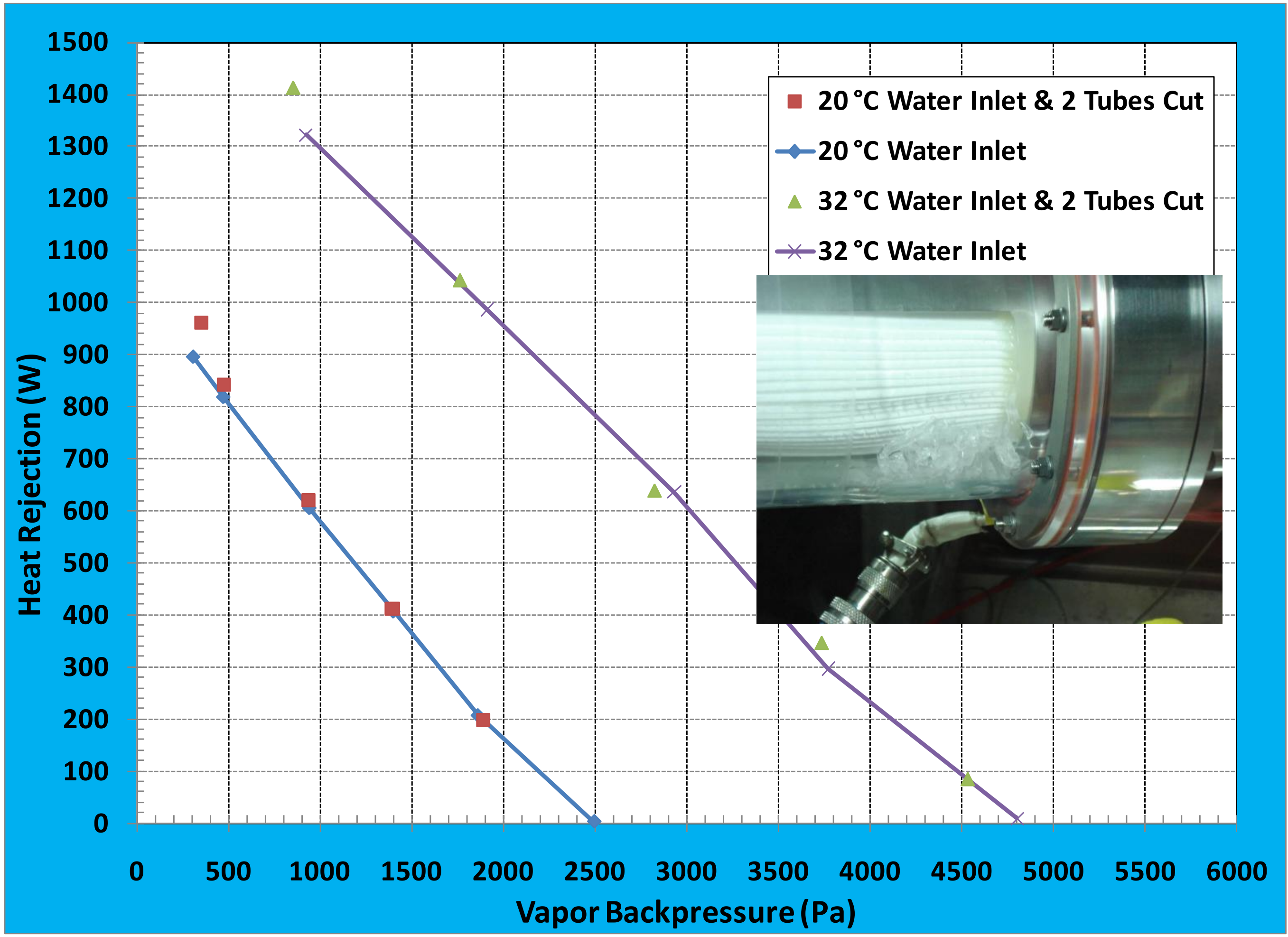
HoFi #1 1 Hour Freeze Test



Cut tube Test Results

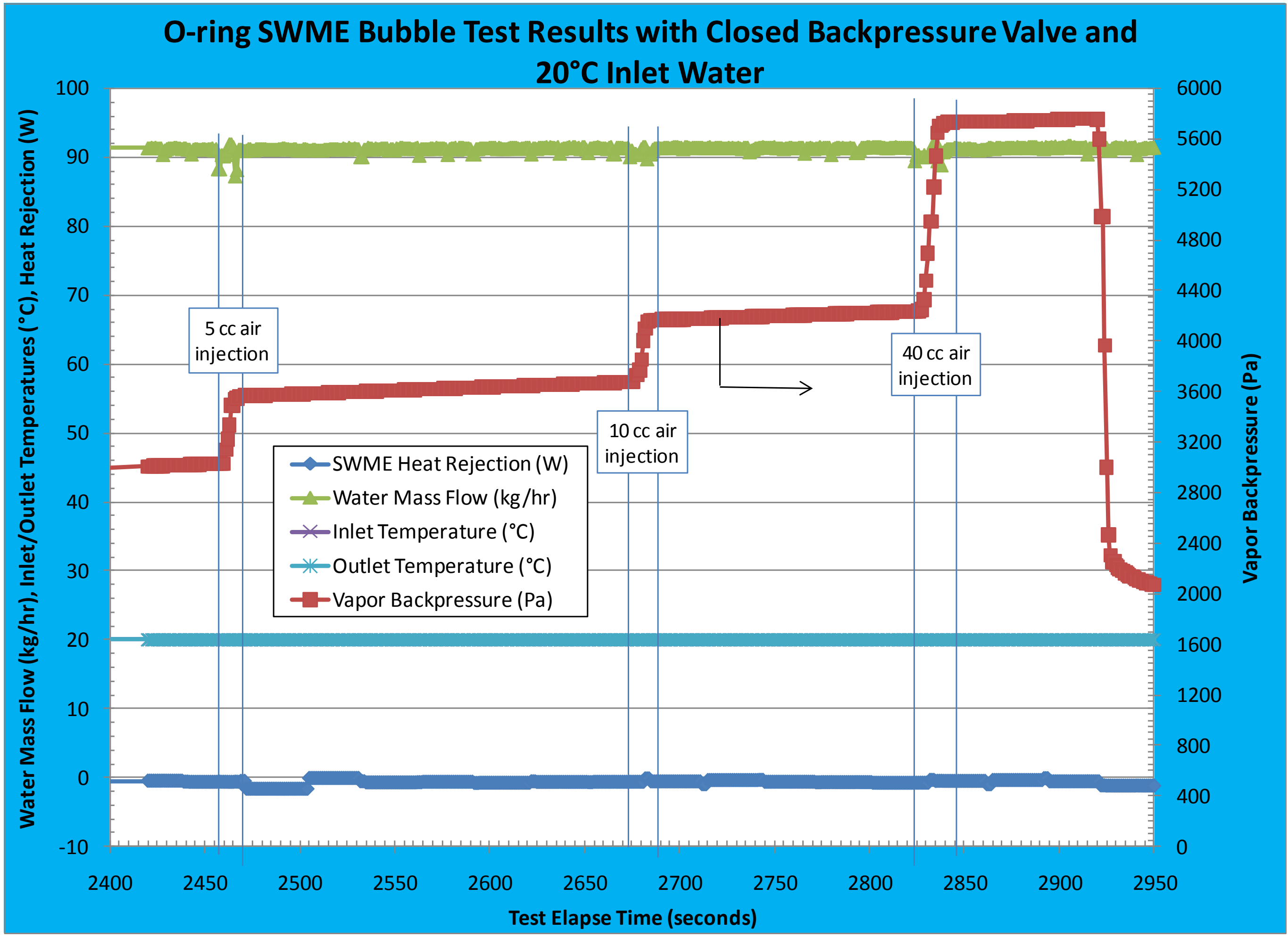
- The normal performance mapping reflects the fact that the uncut tubes were uncompromised by the two cut fibers
- There may have been some local spray evaporative cooling or sublimation of fibers near the cut tubes resulting in a slight boost of performance at the fully open position
- Typical utilization of 93%, dropped to 73% in the cut fiber test: 640 ml of water outflow from just two cut fibers when the intact flow in a single tube is less than 64 ml over the same duration

Heat rejection of HoFi 1 intact and with two tubes cut



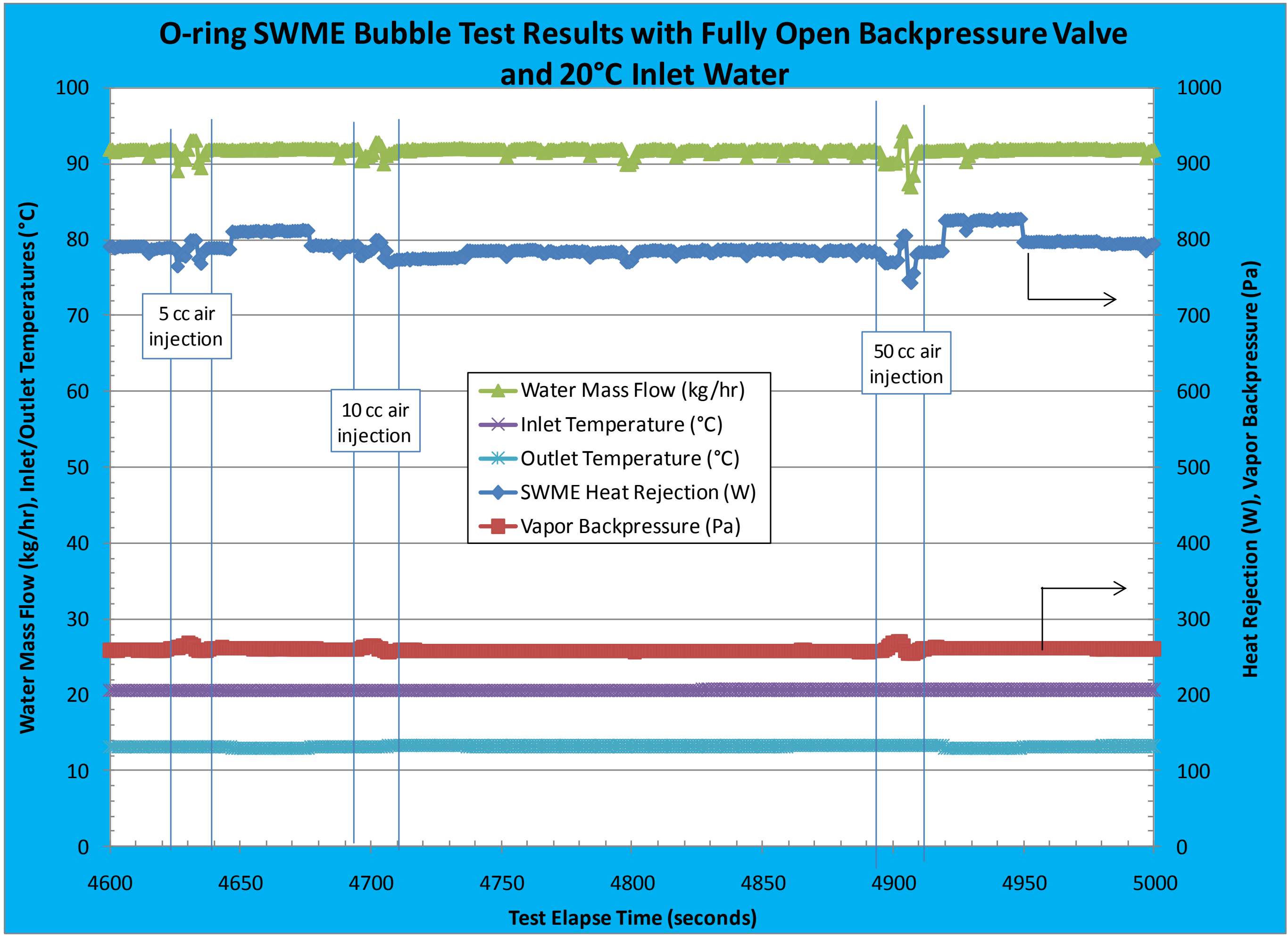
Bubble testing results

- Both systems effectively transferred gas in the water to the vacuum chamber as no bubbles were seen exiting the either system in all test points
- Stable temperatures
- Fully closed valve test results illustrated continuous degassing



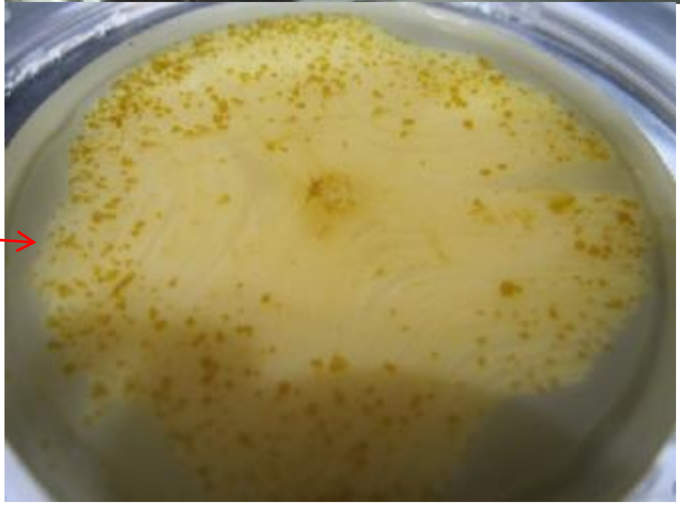
Bubble testing results

- Fully open BPV
- Outlet temp. insignificantly affected
- Mass flow variations expected



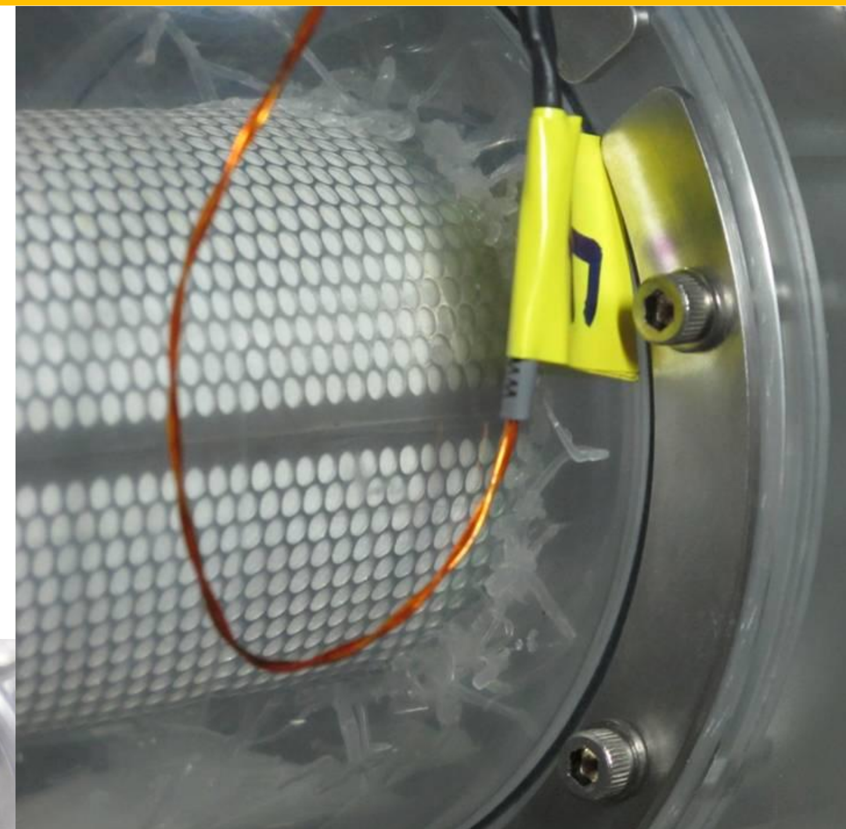
Anomalies: Contamination Test

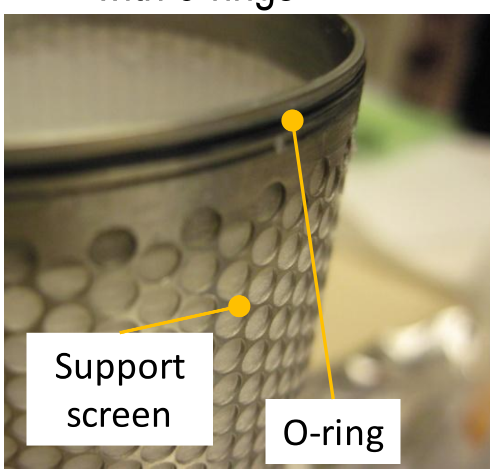
- Anomaly 1: Acid supplied for the Baseline series was 1000X more concentrated than requested, causing corrosion of copper fittings in coolant loop resulting in blue-green stain of nadir fibers
  - Corrected for subsequent tests
- Anomaly 2: Microbial growth lining coolant loop and subsequently killed by antibiotic effect of constituents in 100 EVA water dislodged in single event and partially plugged inlet header
  - Flow reversal unplugged unit and restored pressure drop to nominal levels

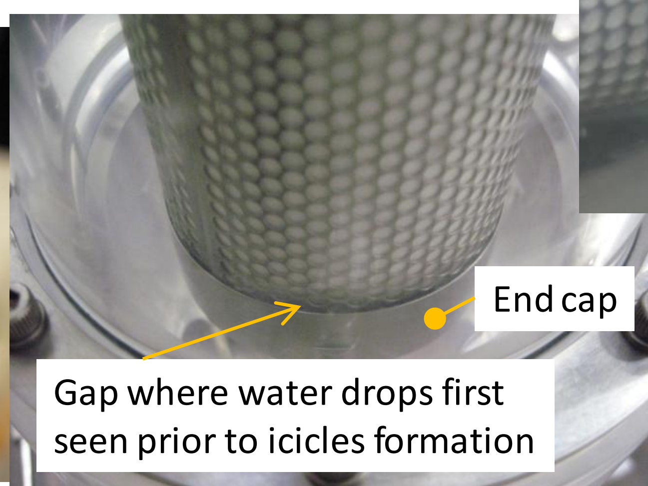


Anomalies: Ice Formation During Hour Long Fully Open BPV Ops (20°C water inlet)

- Started with single small drop between outer annulus outermost membrane screen and end cap
- Drop size sometimes remain in equilibrium for ~2 minutes or grew and fell to bottom of housing
- More drops formed in gap and turned into ice
- Icicles formed afterwards as small jets of water emanated from cap edge
- Usually uniform around the circumference
- Only outer annulus sealed water channel to end cap with o-rings

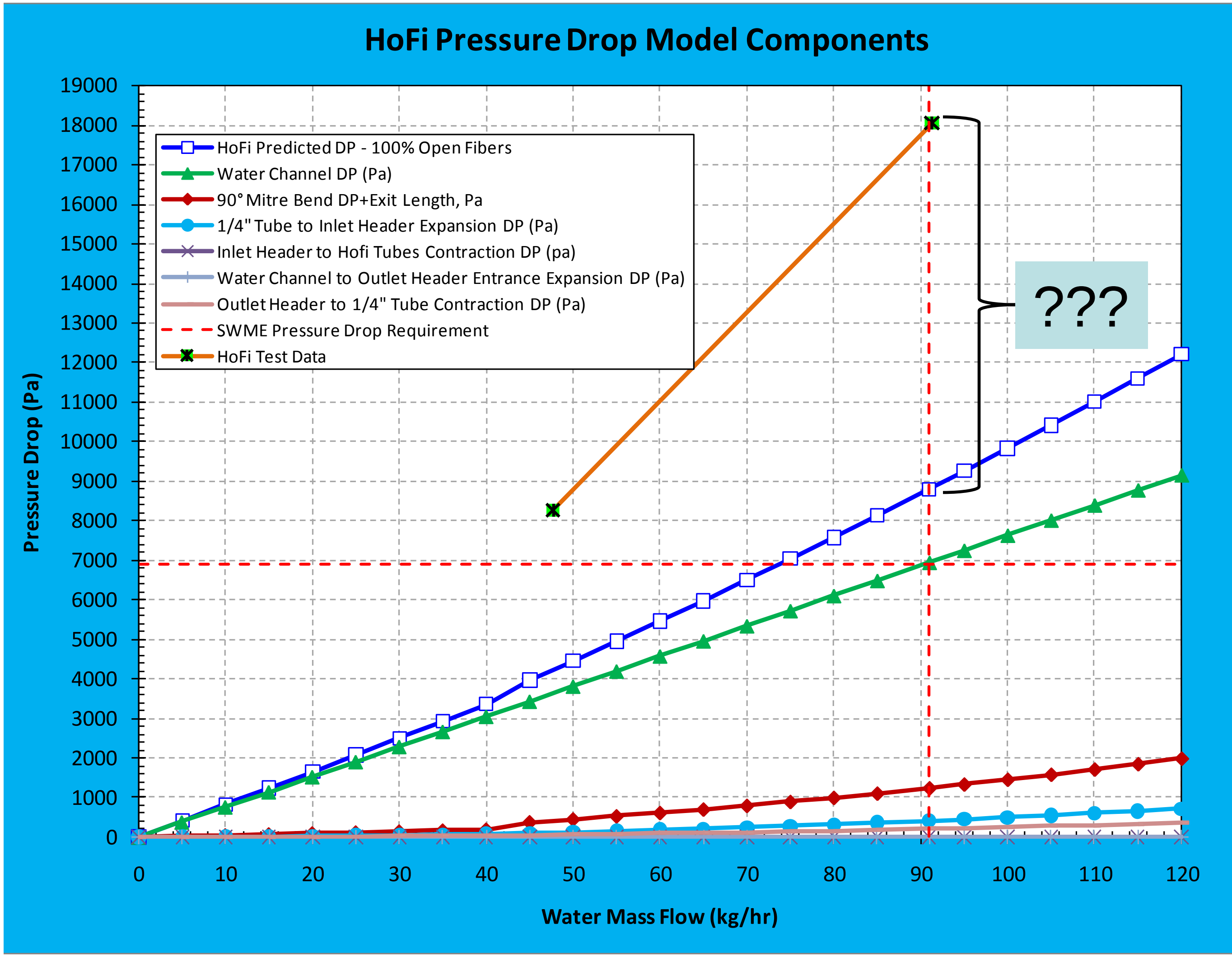




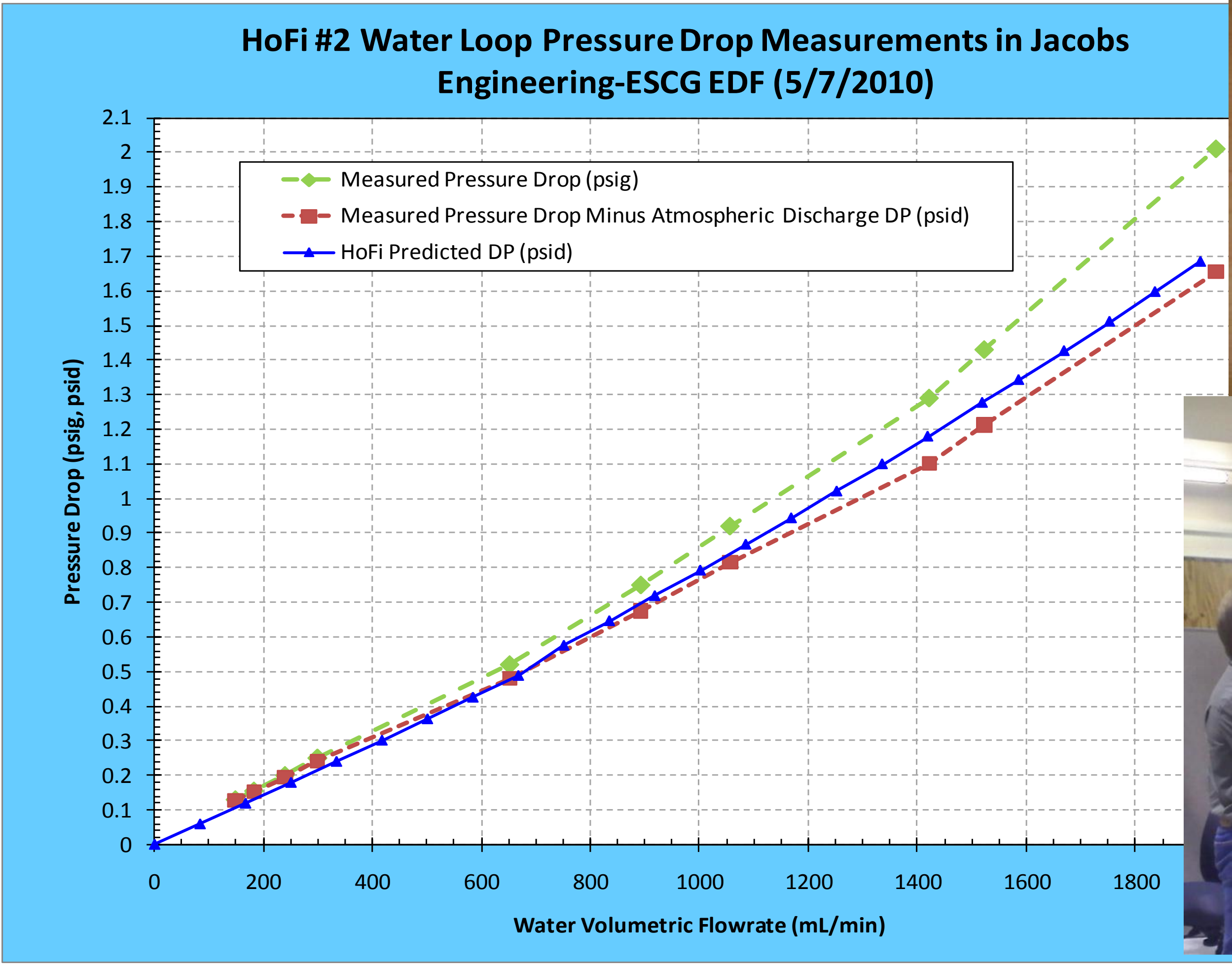


HoFi Water Pressure Drop Verification:

- Measured water pressure drop significantly higher than predictions
- Potential cause for redesign
- Did hydrophobic microchannels behave differently than classical laminar flow theory
  - Research indicated even less pressure drop should be generated
- Small scale HoFi testing and Hofi #2 repeat testing

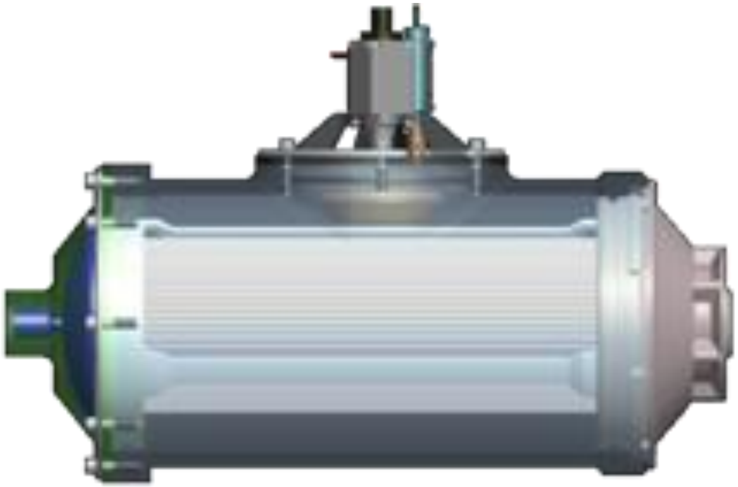


HoFi Water Pressure Drop Verification: No Need for Redesign!



NASA Downselect and Next Prototype

- Both SaM and HoFi units are robust viable full scale systems for advanced spacesuits
- HoFi SWME was selected for further development due to performance edge in vacuum and Mars pressures
  - HoFi pressure drop greater than SaM SWME but still within desired specification
  - HoFi more susceptible to plugging but risk is mitigated with in-line filters



- New HoFi prototype in progress
  - Stainless steel parts replaced with plastic materials to reduce mass,1.54 kg vs requirement of 5.44 kg
  - Backpressure valve moved to side of housing to reduce volume and increase performance, 3 liters vs. requirement of 6.89 liters
  - Combless design compensated by increase in active fiber length, without increasing overall length
  - Tool free access to fiber core for maintenance or replacement