Design and Evaluation of a Water Recirculation Loop Maintenance Device for the Advanced Spacesuit Water Membrane Evaporator

John W. Steele[1] and Tony Rector[2]
Hamilton Sundstrand Space Systems International, Inc., Windsor Locks, CT, 06095

Grant C. Bue[3], Colin Campbell[4] and Janice Makinen[5]
NASA Johnson Space Center, Houston, TX, 77058

A dual-bed device to maintain the water quality of the Advanced Spacesuit Water Membrane Evaporation (SWME) water recirculation loop has been designed and is undergoing testing. The SWME is a heat rejection device under development at the NASA Johnson Space Center to perform thermal control for advanced spacesuits. One advantage to this technology is the potential for a significantly greater degree of tolerance to contamination when compared to the existing sublimator technology. The driver for the development of a water recirculation maintenance device is to further enhance this advantage through the leveraging of fluid loop management lessons learned from the International Space Station (ISS). A bed design that was developed for a Hamilton Sundstrand military application, and considered for a potential ISS application with the Urine Processor Assembly, provides a low pressure drop means for water maintenance in a recirculation loop. The bed design is coupled with high-capacity ion exchange resins, organic adsorbents, and a cyclic methodology developed for the Extravehicular Mobility Unit Transport Water Loop. The bed design further leverages a sorbent developed for the ISS that introduces a biocide in a microgravity-compatible manner for the Internal Active Thermal Control System. The leveraging of these water maintenance technologies to the SWME recirculation loop is a unique demonstration of applying the valuable lessons learned on the ISS to the next generation of crewed spaceflight Environmental Control and Life Support System hardware.[1]

Nomenclature

ACTEX = Activated Carbon Ion Exchange
AEMU = Advanced Extravehicular Mobility Unit
ALCLR = Airlock Cooling Loop Recovery
COTS = commercial off-the-shelf
DI = deionized
ECLSS = Environmental Control Life Support System
EMU = Extravehicular Mobility Unit
EVA = extravehicular activity
HoFi = Hollow Fiber(s)
IATCS = Internal Active Thermal Control System

---

[1] Technical Fellow, Engineering Specialists, 1 Hamilton Road, Windsor Locks, CT 06096-1010/Mail Stop 1A-2-W66
[2] Senior Engineer, Engineering Specialists, 1 Hamilton Road, Windsor Locks, CT 06096-1010/Mail Stop 1A-2-W66
[3] Aerospace Technologist, 2101 NASA Parkway, Houston, TX, 77058/Mail Stop EC2, nonmember
[4] Aerospace Technologist, 2101 NASA Parkway, Houston, TX, 77058/Mail Stop EC5, nonmember
[5] Aerospace Technologist, 2101 NASA Parkway, Houston, TX, 77058/Mail Stop EC2, nonmember

ISS = International Space Station
JSC = Johnson Space Center
L = liter
L/min = liters per minute
LTVC = Leak Test Vacuum Chamber
MF = multifiltration
mg = milligram
NaCl = sodium chloride
OGA = Oxygen Generation Assembly
ppm = parts per million
psia = pounds per square inch absolute
psid = pounds per square inch differential
LCVG = Liquid Cooling and Ventilation Garment
OPA = Orthophthalaldehyde
PEEK = polymer resin bags
PLSS = Primary Life Support Subsystem
NiRA = Nickel Removal Assembly
SMAC = Spacecraft Maximum Allowable Concentrations
SWME = Spacesuit Water Membrane Evaporator
TOC = Total Organic Carbon
TCS = Thermal Control System
VRA = Volatile Removal Assembly
WPA = Water Processor Assembly
WRLMD = Water Recirculating Loop Maintenance Device

I. Introduction

NASA is currently developing an Advanced Extravehicular Mobility Unit (AEMU) under the Advanced Exploration Systems Program. A key part of this development is the spacesuit Primary Life Support Subsystem (PLSS) technology unit that is human-rated for long-duration microgravity or planetary missions, and vacuum or low-pressure environments. A critical component of extravehicular activity (EVA) suits is the Thermal Control System (TCS) that rejects heat from the crew member and electrical components in the PLSS. The current PLSS uses a sublimator for heat rejection. The current PLSS sublimator can effectively cool the crew member and electronics; however, it has a number of limitations, including sensitivity to contaminants, and the need for a separate feedwater supply. Because of these limitations, the current PLSS sublimator is certified for no more than 25 EVAs – critically limiting current EVA capability. Additionally, sublimators do not have the capability of rejecting heat in pressure environments that are above the triple point of water, such as the atmospheric conditions of Mars. The operational goal for the AEMU is for 100 EVAs at 8 hours each, amounting to 800 hours of TCS use. The useful life of the AEMU PLSS is set at 10 years without refurbishment.

The Spacesuit Water Membrane Evaporation (SWME) was developed for the AEMU to meet these challenging requirements. The SWME cools circulating water, which acts as the coolant in the system, through in-line evaporation. The water is then circulated through the liquid cooling garment and also to PLSS components. The SWME takes advantage of recent advances in micropore membrane technology to provide robust heat rejection with a high tolerance to contamination. The SWME design has about 14,900 hollow fibers (HoFi) providing approximately 0.6 m^2 of open pore area. These fibers contribute to resistance of the SWMEe to coolant loop contaminants that will accumulate over the planned 800-hour operational life. The HoFi are thin-walled, porous tubes made from polypropylene that are approximately 300 micrometers (µm) in diameter. The HoFi geometry allows a high-membrane surface area to be contained in a compact module, resulting in a heat rejection device that is durable and reliable.

The first sheet membrane SWME prototype, which was designed and tested at the NASA Johnson Space Center (JSC) in 1999, showed promise for the next-generation heat-rejection subsystem.[1] In 2009, a full-scale version of the sheet membrane prototype was built,[2] together with two full-scale HoFi prototypes.[3] These three prototypes underwent a series of tests to characterize membrane performance, including determination of the cooling water heat-rejection rate, backpressure, results, and contamination sensitivity. In 2010, NASA created a new HoFi SWME prototype called Gen2, based on earlier designs. This Gen2 SWME is built mostly of plastic and has a flight-like valve built into the housing (see Fig. 1).[4] Long-duration testing was also performed, namely 200 hours of stand-alone SWME testing, followed by 400 hours with the same test article in the PLSS 1.0 breadboard testing. These tests included variable metabolic testing to simulate actual EVA use, more severe bubble tests and freeze tests, and Mars atmosphere simulation testing.[4,5]

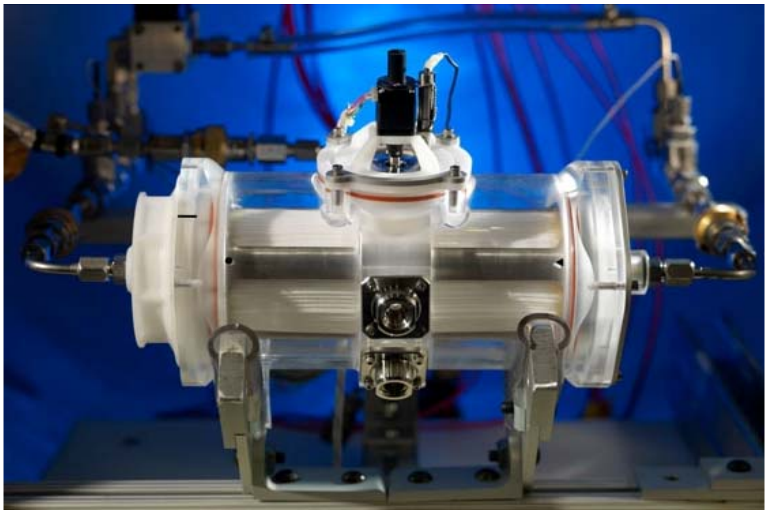

Figure 1. Gen2 SWME.

Table 1 contains the baseline SWME feedwater for these tests. The constituent concentrations were generated with margin based on the capabilities of the ISS Water Processor Assembly (WPA). This feedwater should not be confused with the potable water requirements specified per SSP 41000, Table LVI convey the SMAC that can be tolerated by a human for long durations, whereas the feedwater seeks to require performance with water that include, with some margin, the contaminants reasonably expected to be delivered by the spacecraft WPA to the PLSS. The contamination tests differed from previous testing in that no attempt was made to conservatively project water constituents over the course of 100 EVAs. The circulating coolant was instead allowed to accumulate contaminants over the duration of testing in a flight-like manner, with evaporated coolant being replaced with baseline water similar to that currently available on the ISS.

Table 1. SWME Feedwater

ITEM	Amount (mg/L)
Chemical	
Barium	0.1
Calcium	1
Chlorine	5
Chromium	0.05
Copper	0.5
Iron	0.2
Lead	0.05
Magnesium	1
Manganese	0.05
Nickel	0.05
Nitrate	1
Potassium	5
Sulfate	5
Zinc	0.5
Organic Constituents	
Total Acids	0.5
Total Alcohols	0.5
Total Organic Carbon	0.3

The long-duration performance testing of the SWME yielded variable performance for more than 600 hours.[5] In the stand-alone testing, performance was variable but trended upward to > 800 W of performance at 200 hours of testing. Microbial assay of the circulating water loop show a decrease in colony-forming units consistent with biofilm formation. A month later, with the onset of the PLSS 1.0 testing, SWME performance declined approaching 700 W. Wetted surfaces of fittings in the loop had coatings consistent with biofilm. At the same time, engineers observed an increase in reddish-brown deposits, coincident with pressure drop increases across the SWME and filters. Analysis of these deposits were consistent with corrosion products of non-passivated stainless steel and brazed components, both of which were present in the PLSS 1.0 coolant loop.

The presence of iron, chrome, nickel, and oxygen represents the residue of a system filter that underwent a Scanning Electron Microscope Energy Dispersive Spectrum analysis (Fig. 2), and is indicative of stainless steel corrosion products. Of the two alloys of stainless steel intended for use in the wetted loop (304L and 316L), 304L would be expected to be less corrosion resistant and a more likely source of the corrosion products. Commercial off-the-shelf (COTS) parts containing pump shafts, QDs, pressure transducers, and manual valves tend to contain less corrosion-resistant stainless steels (15-5 PH and 17-4 PH) and could not be ruled out as sources of the stainless steel corrosion products at the time of this writing. Copper and zinc were also observed in the analysis, and the two found together are generally indicative of the presence of brass, though 15-5 PH and 17-4 PH stainless steels also contain 3 – 5 weight percent copper and could not be ruled out as the source of copper.

While bubble testing midway in the stand-alone SWME tests showed strong bubble clearing capability, subsequent tests late in the long-duration testing showed that this capability had been completely lost. At the end of the PLSS 1.0 testing, droplets of coolant were observed on the exterior of the SWME fibers, suggesting some loss of the hydrophobicity of the membranes.

These findings have underscored the need for careful control of materials in coolant loop designs for long-duration testing and PLSS 2.0. Wetted metallic surfaces of the circulating loop will be made of passivated 316L stainless steel. Plastic tubing will also be screened to avoid contamination from leachates. The need for consistent biocide control is also a necessary consideration for the water quality because the baseline water supply from the WPA will contain organic material that will tend to concentrate with evaporation and coolant resupply from normal SWME operation. Silver and iodine have been used for biofilm control in current spacesuit programs, but they are not recommended for long-duration operation because they tend to be eliminated by exposure to metals and organic polymers, both of which are present in the AEMU coolant loop design. The PLSS 2.0 program seeks to investigate the efficacy of Orthophthalaldehyde (OPA) biocide to provide stable biofilm control, as has been shown to be successful for the water loop of the ECLSS system on the ISS. This process would be coupled with periodic cleaning of the circulating loop with anion/cation exchange resin and activated carbon beds, followed by recharging the loop with OPA, a system Water Recirculating Loop Maintenance Device.

Testing is in progress to evaluate the long-duration performance of two SWME systems in parallel coolant loops, one with proper material control only and the other with both material control and biofilm and water quality control, as described above. This testing will inform the design and maintenance requirements for the vehicle systems that service the AEMU.

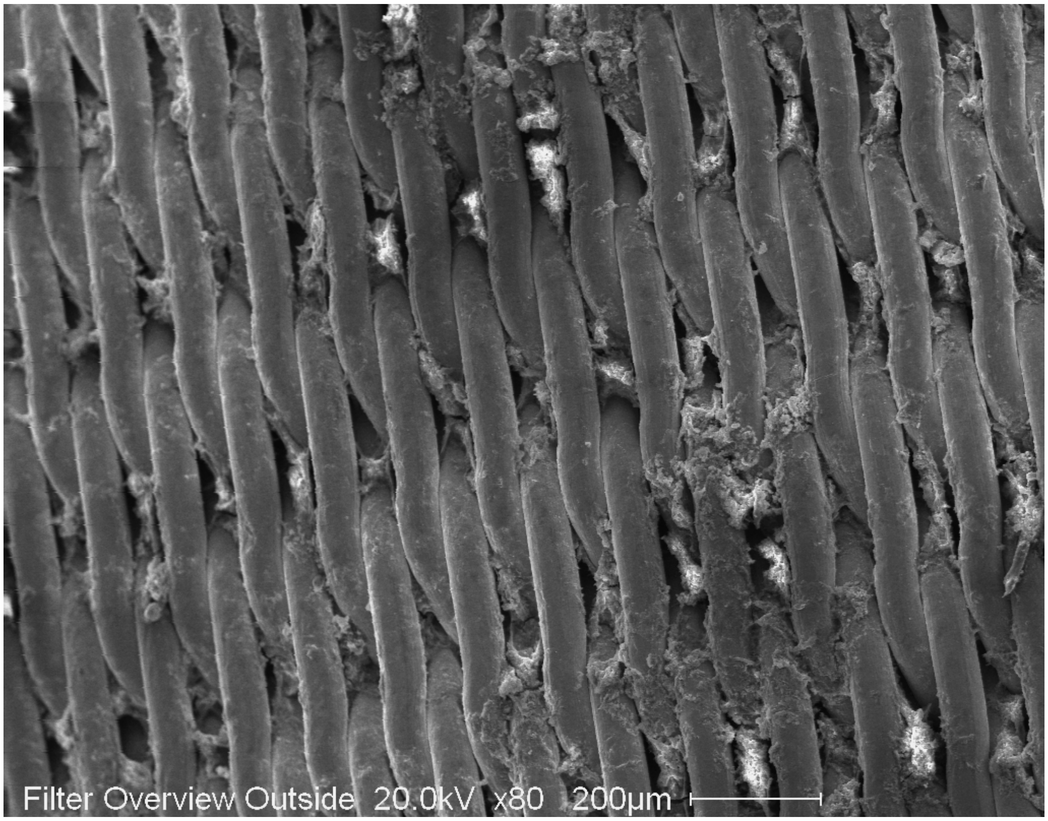

Figure 2. Scanning electron microscope image of SWME filter.

II. International Space Station Technologies Pertinent to Spacesuit Water Membrane Evaporation Recirculation Loop Needs

A number of technologies that have been developed for the Extravehicular Mobility Unit (EMU) and ISS ECLSS hardware that contain fluid loops are potentially applicable to SWME water recirculation loop contamination control. The use of proven technologies and lessons learned for next-generation ECLSS hardware with fluid loops is a prudent means to reduce and/or mitigate long-term performance risk.

The Airlock Cooling Loop Recovery (ALCLR) water processing kit is the first such technology pertinent to the long-term successful performance of the SWME water recirculation loop. The ALCLR was developed as a corrective action to EMU coolant loop flow disruptions experienced on the ISS in May 2004 and thereafter.[6] The components in the kit are designed to remove the contaminants that caused prior flow disruptions. ALCLR water processing kits have been used since 2004 as standard operating procedure, with periodic analysis of EMU coolant loop water and hardware examinations as a means to determine adequate functionality, optimized processing cycles, and ALCLR component shelf-life.[7]

The ALCLR water processing kit (Fig. 3) was devised to scrub and remediate the various chemical and biological contaminants and by-products that were found to have fouled the magnetically coupled pump in the EMU Transport Loop Item-123 Fan/Pump/Separator. The heart of the kit is the EMU Ion Filter, which is a 50:50 by volume packed bed of mixed anion/cation exchange resin and activated carbon. This component is periodically installed into the EMU/Airlock Heat Exchanger coolant loop and serves the purpose of removing inorganic and organic constituents such as nickel and iron corrosion products and organic acids with the ion exchange resin. Furthermore, uncharged organic contaminants are removed with the activated carbon.

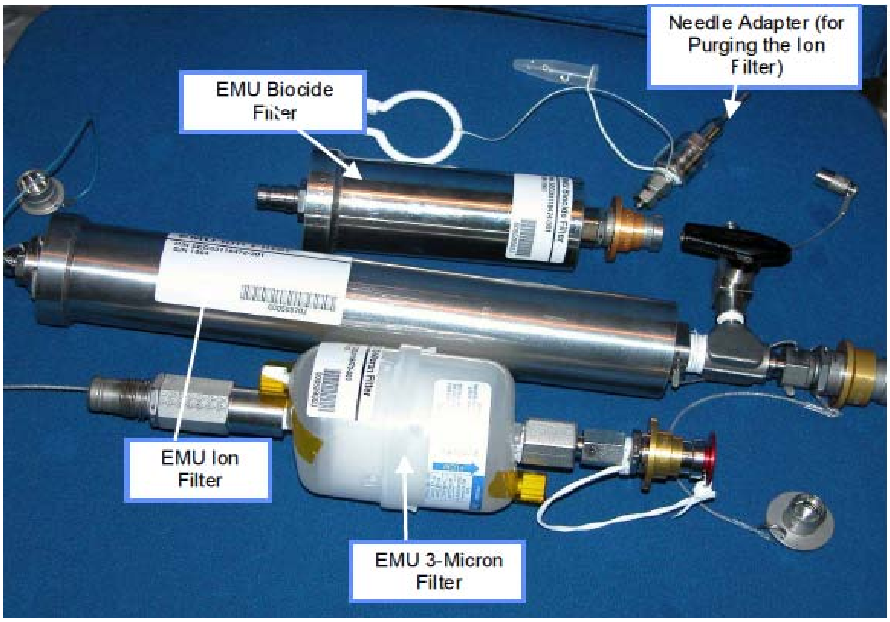

Figure 3. ALCLR processing kit components.

In service, a 3-μm filter is placed downstream of the EMU Ion Filter to capture fines from the packed bed prior to return of the polished water to the EMU Transport Loop. The EMU Biocide Filter is installed, after scrubbing with the EMU Ion Filter, to add residual iodine biocide for microbial control. The EMU Biocide Filter is a packed bed of ion exchange resin impregnated with iodine

The ALCLR is actually a hybrid of another scrubber bed currently used on the ISS for the removal of iodine and iodide from WPA effluent water, the Activated Carbon Ion Exchange (ACTEX). The ACTEX has more recently been incorporated into the Oxygen Generation Assembly (OGA) feedwater loop to scrub trace hydrofluoric acid by-products of the operational cation-exchange Nafion® membrane used in the OGA cell stack and to balance pH of the recirculation water. Furthermore, the ACTEX use in the OGA recirculation loop reduces the impact of low-level cationic corrosion product poisoning of the cell stack Nafion® membrane.[8]

Another pertinent technology to the SWME water recirculation is a biocide-impregnated substrate that has been developed to impart a biocidal concentration of the biocide OPA to a fluid-loop on orbit, specifically the ISS Internal Active Thermal Control System (IATCS). The proliferation and growth of microorganisms in the IATCS aboard the ISS has been of significant concern since 2003. NASA has conducted previous investigations to select a biocide that would sufficiently control the microbial communities currently observed in the IATCS. Those evaluations were conducted on candidate biocidal agents that could mitigate existing microbial concerns while meeting other selection criteria (i.e., system compatibility, toxicity, etc.) set forth as requirements. The resultant biocidal agent selected from these studies was OPA – an aldehyde-based organic molecule that contains sufficient biocidal properties with respect to a wide range of microbial organisms and meets system compatibility issues related to the IATCS.[9]

A key aspect of the biocide use on the ISS was the method in which the biocide would be delivered to the coolant system. A non-intrusive implementation technique needed to be developed to add the OPA to the IATCS. The method developed used the current Nickel Removal Assembly (NiRA) packed bed hardware. An immobilization of the OPA to an inert resin substrate was then selected as the process to package for delivery. Development of the immobilization procedure encompassed determining proper OPA loading density to the resin material as well as proper placement of the biocide-loaded resin in the packed bed to meet both elution profile and final concentration requirements. Significant ground testing at both 1/10th and full-scale levels demonstrated that adequate concentrations could be added to the IATCS in the required time envelope while maintaining compliance with system requirements.[9]

In addition to developing OPA delivery resin material, NASA investigated the means to adequately determine on-orbit aqueous OPA concentrations. Spot check biocidal concentrations was deemed imperative, due to the extreme time lapse experienced when on-orbit samples require ground verification. A test strip was developed for a wide range of OPA concentrations and was successfully manufactured for on-orbit use. The OPA delivery resin and tests strips were delivered to the ISS on flight 10A and subsequently used during that mission.[9]

Finally, NASA has developed an alternative to a conventional packed bed for several low pressure-drop applications, including a next generation ALCLR bed for the EMU. An alternative to scrubbing the ISS OGA recirculation loop is under evaluation. This cassette bed approach (Fig. 4) is of potential use in SWME water recirculation loop in that it has been shown, experimentally, to result in efficient kinetic rates and low pressure drop. The design consists of thin cassettes that house ion-exchange resin parallel to the SWME recirculation water flow path, which maintains a low pressure drop.[10]

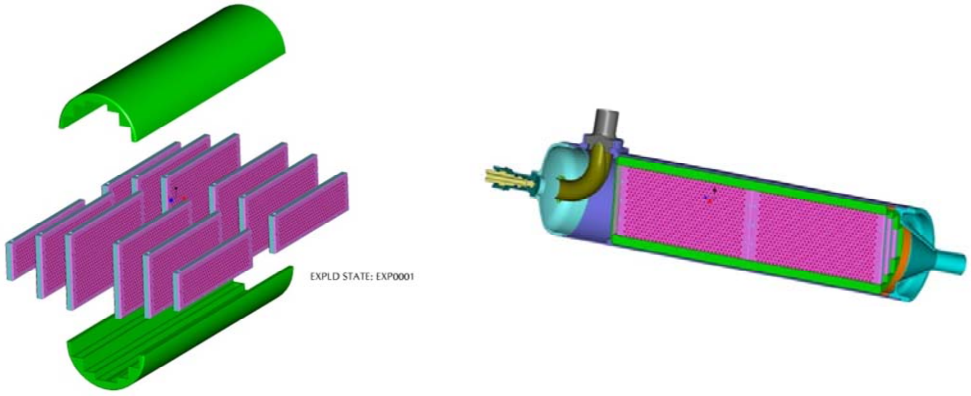

Figure 4. Low pressure drop cassette-style ion exchange bed.

III. Spacesuit Water Membrane Evaporation Water Loop Maintenance

The primary purpose of the SWME water loop maintenance activity is to remove dissolved inorganic ions that can cause detrimental impacts to the SWME or associated components in the recirculation loop. These inorganics are introduced by the influent water source, corrosion of metallic components in the water loop, and possible other water streams that communicate with the SWME. Mixed ion exchange resins can be used to mitigate the inorganic contamination. These resins have the ability to remove charged species (anion and cation) from solution by exchanging H^+ and OH^- groups, which also allows the pH to remain near neutral. An additional concern, due to coolant fluid being water, is the proliferation of microbiological growth in the recirculation loop. To mitigate this concern, biocides can be added, which can inhibit or control the growth of microorganisms. These activities, ion exchange and biocide introduction, are currently used in the ALCLR setup with the EMUs aboard space station as well as in the ISS IATCS (in the case of biocide addition) to maintain the recirculation water loops. [6,7]

For the SWME recirculation loop, an ion exchange bed, biocide delivery bed, and biocide removal bed were developed to aide in maintaining the water quality. The ion exchange bed is a novel, low-pressure drop bed, which uses a segmented geometry to reduce the associated pressure drop. The biocide addition bed uses an organic biocide, OPA, which was developed for the IATCS on the ISS to control microbiological growth. Additionally, an activated carbon bed was also developed to remove residual biocide, associated reaction products of the biocide and other organics present in the water loop. These beds will maintain the water quality of the SWME loop when used at prescribed intervals. [8,9]

A proof-of-concept, low-DP ion exchange bed was developed for use in the SWME test system at JSC. The ion exchange bed was constructed primarily out of polycarbonate, with the only exceptions being the stainless steel cassette screens (304SS) and the polymer resin bags (PEEK). The bed has a diameter of 7 cm (2.75 in.) and an overall length of 25.4 cm 10 in.). Four individual cassettes of two different sizes are located nside the bed; one pair is 6.4 cm (2.5 in.) in height and the other pair is 3.81 cm (1.5 in.) in height, with both sets having overall lengths of 7.5 in (19 cm). A photo of the SWME ion exchange bed and a similar prototype bed is displayed in Fig. 5. The cassettes are help in place inside the cylindrical housing using cassette retainers made from perforated polycarbonate sheet. These retainers also allow for flow distribution at the inlet of the bed. The ion exchange resin is contained in PEEK mesh bags that have an approximate mesh size of 60, corresponding to an open area of 56%. The mesh bags were packed with approximately 100 cm^3 of total ion exchange resin and are stitched closed. The bags were then placed in the polycarbonate cassette frames and secured with the outside 304SS cassette screens. The overall volume of the SWME ion exchange bed was 450 cm^3 and the bed was proofed to a pressure of 40 psig.

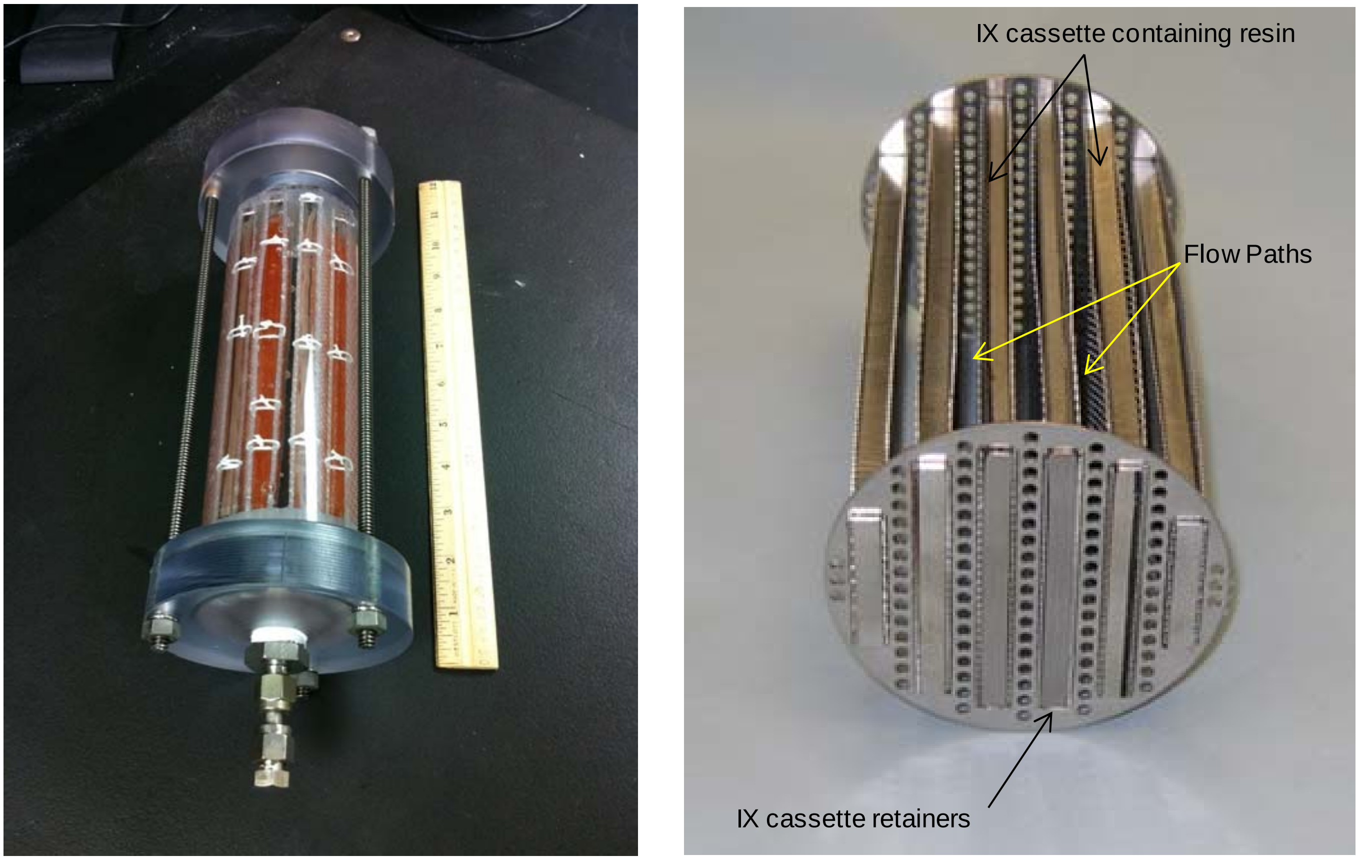

Figure 5. (A) SWME ion exchange bed; (B) initial low DP ion exchange bed prototype.

Performance tests were conducted prior to the delivery of the low DP ion exchange bed to the SWME team at JSC, These tests included the determination of operational pressure drop and the removal efficiency of a dissolved inorganic salt challenge. The pressure drop evaluation was conducted at a range of flow rates that also captured the expected flow rate of the SWME test system (1.5 liters per minute (L/min0). The test showed that at the anticipated operational flow rate of 1.5 L/m in the DP approximately 0.18 pounds per square inch differential (psid) (1.24 kpa) (Fig. 6). Removal efficiency tests were also conducted on a 2-L closed flow loop. In this test 100 milligrams-sodium chloride (NaCl)/L was added to the fluid loop to establish the challenge solution. During the test, conductivity was measured to monitor the uptake of the NaCl by the ion exchange bed. During initial testing, it was observed that the removal rate was significantly lower than anticipated. It was determined that considerable channeling was occurring in the ion exchange bed. This was primarily due to the lack of a flow equalization zone in the inlet area of the bed. It was envisioned that the cassette retainers would allow for adequate flow distribution. To mitigate this issue, a baffle was placed in a central position in the bed to facilitate better flow distribution. Follow-on testing indicated that the baffle should be located closer to the inlet to achieve the desired flow characteristics (Fig. 7).

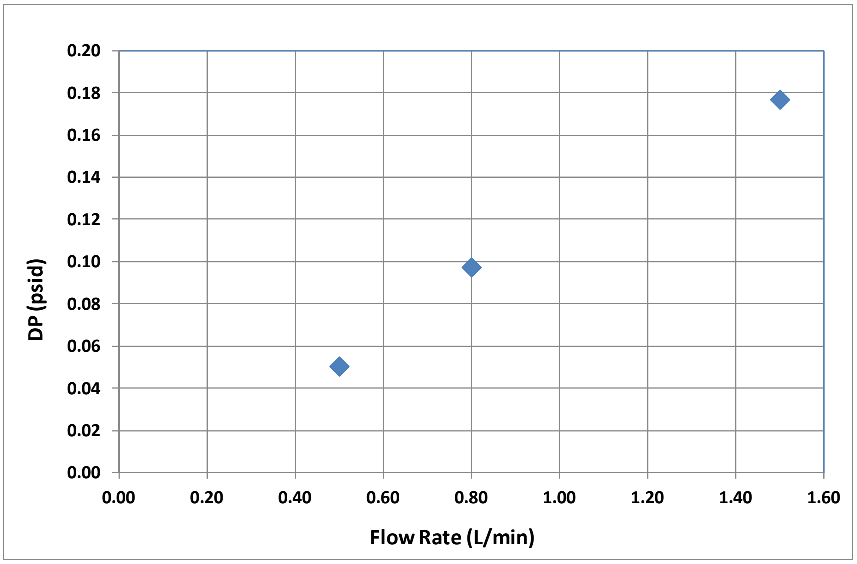

Figure 6. Pressure drop across ion exchange bed.

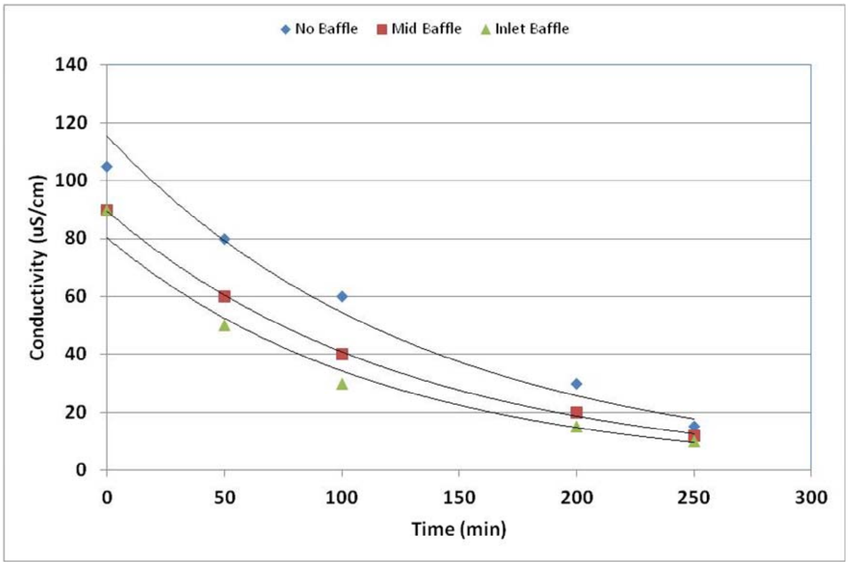

Figure 7. Removal efficiency with various baffle configurations.

Water samples from the first generation SWME test bed were obtained and analyzed at HS (Table 2). The results show that the concentration of introduced ions increases over time as the SWME operates. Results from microbiological testing are currently pending.

Table 2. Results of Water Chemistry After 600 Hours of Run Time on the SWME

SWME Water Analysis			
		Total	Dissolved
TC	13.98 ppm		
TOC	6.68 ppm		
TIC	7.30 ppm		
Cond	460 uS/cm		
Fe		0.52 ppm	<0.05 ppm
Cr		<0.05 ppm	<0.05 ppm
Ni		3.25 ppm	3.07 ppm
Al		<0.05 ppm	<0.05 ppm
Zn		2.35 ppm	1.59 ppm
Si		0.18 ppm	0.17 ppm
F	0.30 ppm		
Cl	64.34 ppm		
NO2	<0.05 ppm		
SO4	90.86 ppm		
NO3	7.01 ppm		
PO4	<0.05 ppm		
Li	<0.05 ppm		
Na	0.46 ppm		
NH4	0.44 ppm		
K	68.96 ppm		
Ca	9.51 ppm		
Mg	6.92 ppm		
NVR	28.17 mg/100 mL		

A biocide delivery resin was developed, due to the proliferation and growth of microorganisms in the IATCS aboard the ISS. This resin was developed using the biocide OPA, which was immobilized on a methyl-methacrylate-based resin material. This immobilized resin was then packed in an existing canister and when placed in the IATCS would elute to the fluid stream to a desired concentration. Typical elution profiles for the IATCS call for elution of 100 mg-OPA/L into the IATCS; however, levels of up to 300 mg-OPA/L are also used in various loops of the IATCS aboard the ISS to keep microbiological population in check (Fig. 8). The concentration of OPA eluted from the resin material is directly related to the volume of the coolant loop being treated and the amount of OPA delivery resin packed into a canister. This elution relationship has been extensively tested and proven consistent for all applications of the OPA biocide. While the OPA biocide was developed for IACTS use, the biocide's safe and efficient elution ability makes it a potential candidate for other fluid streams requiring periodic maintenance to control microorganisms. [8,9]

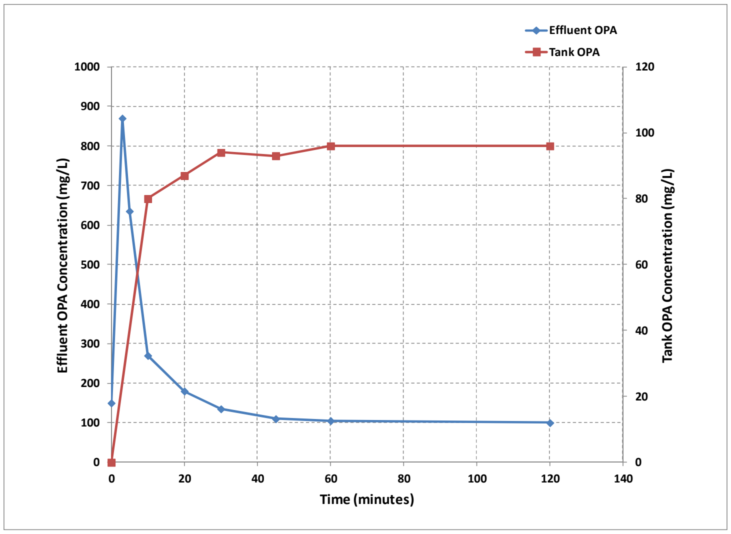

Figure 8. Elution profile for OPA delivery resin. Typical target concentrations are 100mg-OPA/L.

The duty cycle selected for the current SWME test is still pending. The anticipated plan of action is to sample the SWME water loop on a weekly basis. Following a review of the analysis results of each sample, the team will determine the appropriate course of action. A predetermined cycle will be better established following real-time samples from the SWME loop.

IV. To-date Results

The test bed for the WRLMD has been built up in the Leak Test Vacuum Chamber (LTVC) at JSC in the Space Suit Systems Laboratory in Building 7, Room 348. The LTVC has two identical, parallel, independent, closed coolant loops, each with a pump, a heat exchanger with chiller cart, a feedwater tank, main and trim heaters, and various instruments. The heat exchanger and chiller cart provide coolant fluid flow and heat load to quickly condition the loop at the beginning and end of each test. The main and trim heaters are used to add a heat load to the test loops.

Figure 9 is a schematic of the test loop illustrating the SWME test article, other major components, and instrumentation. The SWME water inlet temperatures will be maintained the main and trim heaters. The main heater is a 1000W immersion heater. The trim heater consists of 50W heater tap wrapped around a run of stainless steel tubing directly upstream of the vacuum chamber. Make-up water is continuously supplied as needed from the reservoir feedwater tanks as feedwater is evaporated.

The reservoirs are weighed daily at test beginning and end to calculate total water evaporation. The water flow rate is controlled by adjusting the pump motor speed controller. The flow rate is monitored by micro-motion Coriolis flow-meters. SWME heat rejection rates are controlled by the backpressure valve, which, when adjusted, will change the SWME vapor side pressure which is also referred to as backpressure. COTS Membrane Evaporator backpressure is adjusted by size of the main engine orifice.

Backpressures will range from water saturation pressure corresponding to inlet temperatures (when the valve is closed), to values less than the water triple point pressure (when the valve is fully opened).

The two SWMEs are equipped with thermistor temperature sensors to accurately measure the inlet and outlet water temperatures. The SWMEs are also equipped with pressure transducers to accurately measure the outlet pressure of the test article and the chamber pressure. A flow meter in the water system will be used to measure the system flow rate, and a scale will be used to measure the quantity of water in the accumulator tank. A rack-mounted, computer-based data acquisition system is used to monitor and to record both facility and evaporator parameters shown in Table 3.

Table 3. Critical Test Parameters

PARAMETER	RANGE	Accuracy	UNITS
Backpressure	0 – 100	0.05%	Torr
Chamber Temperature	-250 – 350	0.5	°C
Make-up Water Weight	0 – 200	0.01% FS	kg
Chamber Pressure	0-1000	0.19%	Torr
Water Flow Rate	50 – 113	0.5%	kg/hr
Test Article Inlet Temperature	0 – 100	0.01	°C
Test Article Outlet Temperature	0 – 100	0.01	°C
Test Article Inlet Pressure	0 – 25	10%	psia
Test Article Delta Pressure	0 – 5	10%	psid
Pump Delta Pressure	0-15	10%	psid

One of the circulation loops, the test loop, is serviced by the WRLMD, while the other, the control loop, is not. Aside from the WRLMD service, the test and control loops are run simultaneously and as close to identical as possible. Both loops are run with 91 kg (200 lb)/hr with a 10°C (50°F) outlet temperature. Aside from a daily 10-minute, fully-open valve test to gauge SWME performance degradation, performance is maintained at 264 W of heat rejection for each system. Circulating water is tested on a weekly basis to determine OPA concentration and water analysis. The results of the weekly water analysis determine when the servicing by the WRLMD will be conducted.

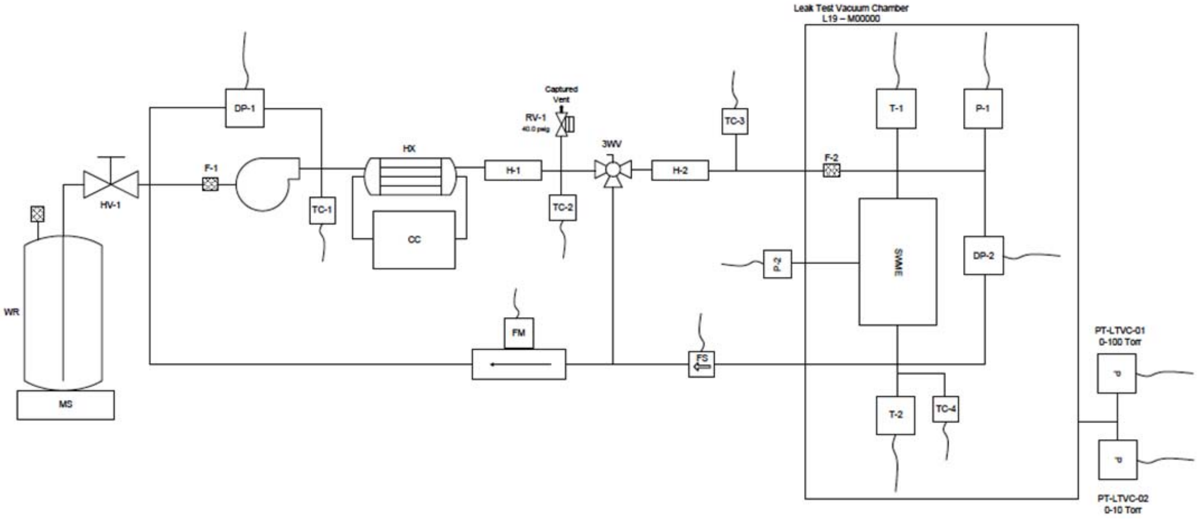

Figure 9. Schematic of leak test vacuum chamber circulating loop (one of two shown).

V. Future Plans

The parallel testing of the control and test loops will continue until at least 800 hours of operation are completed. The maintenance schedule established for the LTVC test loop will be used in future tests – in particular, the PLSS 2.0 test series. The success in controlling the water quality in the circulating loop will help to justify the development of a flight system WRLMD for the AEMU.

VI. Summary

The SWME represents an evolution in EMU cooling technology, with to-date results demonstrating a reduced sensitivity to feedwater contaminants when compared to the current EMU sublimator. The reduced sensitivity to contaminants, however, does not negate the importance of feedwater quality to optimize performance of the SWME and the AEMU thermal control system, including the Liquid Cooled Garment. To that end, an effort is under way to leverage EMU and ISS developed water quality maintenance technologies to maintain the health of the SWME water recirculation loop.

Technology developed and used for the EMU Transport Water Loops and the ISS IATCS are coupled with a novel, low-pressure-drop scrubber bed design to provide a water quality maintenance capability referred to as the WRLMD. Testing is under way to evaluate performance of this hardware and to develop an optimal duty cycle in the JSC Space Suit Systems Laboratory in Building 7, Room 348, LTVC. Results of this testing will be used to evolve the WRLMD in concert with the AEMU SWME.

References

[1] Ungar, E. K., and Thomas, G. A., “Design and Testing of a Spacesuit Water Membrane Evaporator,” *Proceedings of the 2001 Nation Heat Transfer Conference*, ASME, 2001.

[2] Vogel M., Vonau W., Trevino L., and Bue G., “Sheet Membrane Spacesuit Water Membrane Evaporator Design and Thermal Tests,**”** AIAA-2010-6039, 40th International Conference on Environmental Systems, Barcelona, Spain, July 2010.

[3] Bue G.; Trevino L., Tsioulos G., Settles J., Colunga A., Vogel M., and Vonau W., “Hollow Fiber Spacesuit Water Membrane Evaporator Development and Testing for Advanced Spacesuits,” AIAA-2010-6040, 40th International Conference on Environmental Systems, Barcelona, Spain, July, 2010.

[4] Bue G.; Makinen J., Vogel M., Honas M., Dillon P., Colunga A., Truong L., Porwitz D., and Tsioulos G., “Hollow Fiber Flight Prototype Spacesuit Water Membrane Evaporator Design and Testing” AIAA-2011-5259, 41st International Conference on Environmental Systems, Portland, Oregon, July, 2011.

[5] Bue G.; Makinen J., Cox M., Watts C., Campbell C., Vogel M., and Colunga A., “Long Duration Testing of a Spacesuit Water Membrane Evaporator Prototype” submitted for publication, 42st International Conference on Environmental Systems, San Diego, California, July, 2012.

[6] Lewis, J. F., Cole, H., Cronin, G., Gazda, D. B., Steele, J. W., “Extravehicular Mobility Unit (EMU)/ International Space Station (ISS) Coolant Loop Failure and Recovery”, ICES Paper, 2006-01-2040.

[7] Steele, J.W., Rector, T., “Airlock Cooling Loop Recovery (A/L CLR) Sampling and Analysis Results – Phase II”, Hamilton Sundstrand Internal Document SVME: 6057H.

[8] OGA 2012 ICES Paper

[9] Rector, T., Steele, J., and Wilson, M., “ISS IATCS Coolant Loop Biocide Implementation,” SAE Technical Paper 2008-01-2159, 2008.

[10] Rector, T., Beringer, D., Steele, J., “Ion Exchanger Reactor,” U. S. Patent 7,857,979, 2010, (European Patent 08250615.5 – 1213, 2008).