Abstract

Redesign of the Extravehicular Mobility Unit Airlock Cooling Loop Recovery Assembly

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During EVA (Extravehicular Activity) 23 aboard the ISS (International Space Station) on 07/16/2013 an episode of water in the EMU (Extravehicular Mobility Unit) helmet occurred, necessitating a termination of the EVA (Extravehicular Activity) shortly after it began. The root cause of the failure was determined to be ground-processing short-comings of the ALCLR (Airlock Cooling Loop Recovery) Ion Beds which led to various levels of contaminants being introduced into the Ion Beds before they left the ground. The Ion Beds were thereafter used to scrub the failed EMU cooling water loop on-orbit during routine scrubbing operations. The root cause investigation identified several areas for improvement of the ALCLR Assembly which have since been initiated. Enhanced washing techniques for the ALCLR Ion Bed have been developed and implemented. On-orbit cooling water conductivity and pH analysis capability to allow the astronauts to monitor proper operation of the ALCLR Ion Bed during scrubbing operation is being investigated. A simplified means to acquire on-orbit EMU cooling water samples has been designed. Finally, an inherently cleaner organic adsorbent to replace the current lignite-based activated carbon, and a non-separable replacement for the separable mixed ion exchange resin are undergoing evaluation. These efforts are undertaken to enhance the performance and reduce the risk associated with operations to ensure the long-term health of the EMU cooling water circuit.

Nomenclature

ALCLR = Airlock Cooling Loop Recovery
COTS = Commercial off the shelf
EMU = Extravehicular Mobility Unit
EVA = extravehicular activity
FPS = fan/pump/separator
ISS = International Space Station
JSC = Johnson Space Center
LCVG = Liquid Cooling and Ventilation Garment
pH = hydrogen ion concentration
ppm = parts per million
SEMU = Short Extravehicular Mobility Unit
TOC = Total Organic Carbon
uS = micro-Siemens

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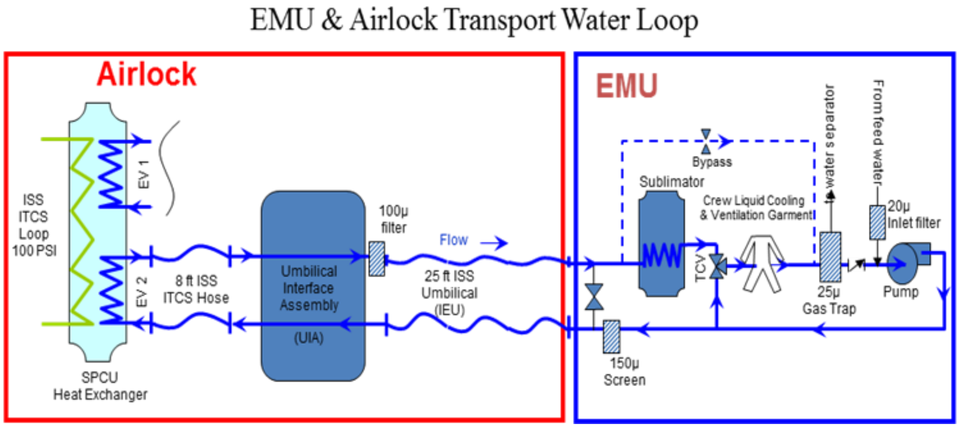
Overview of the EMU Transport Loop

The EMU Feed-water loop provides water to a Sublimator porous plate for system cooling. Heat is rejected by the sublimation of the Feed-water water to the vacuum of space. The Feed-water tank provides roughly 8.4 lbs of water for cooling along with storing crew respiration and perspiration condensate from the ventilation loop. The Transport Water Loop transfers the crew heat load to a Sublimator for cooling. Crew thermal comfort is manually controlled by varying the Transport Water flow to the Sublimator. (see Figure 1)



EMU Feed water Loop

Figure 1. EMU Transport Water Plumbing Schematic

Maintaining the EMU transport water loop for long-term (6 year) operation presents the EMU team with significant challenges. The known risks to the loop, risks inherent in the current ISS mission, can be identified by past failures and by examining the interfaces between the EMU and ISS systems. The Fan/Pump/Separator and key transport loop filters have failed due to contaminants and corrosion products that are produced by EMU wetted components and by the ISS Airlock's Low Temperature Loop Heat Exchanger which provides cooling water for suited crewmembers prior to activating the EMU's Sublimator. These failures are made more likely by extended stagnation time of the water in the EMU water loops.[2]

In the past there have been contamination issues with water originating from ISS spanning from contamination originating in the airlock heat exchanger, to unexplained increases in TOC. Each of these events was unexpected and required post-event remediation, new maintenance procedures, and hardware and (ground) testing to keep the EMU system viable.[2]

In 2003 EMU serial numbers 3005, 3011 & 3013 were left on-board the ISS after the Columbia accident and began to experience significant performance degradation and failure within approximately a year after being initially charged with water and launched to the ISS. The EMU hardware fan/pump/separators were not able to function. After extensive testing of the water in the system, and invasive forensic determination of the source of contaminates that had deposited on the fan blade, it was determined that the ISS Airlock heat exchanger was releasing nickel and silicon into the water and depositing in the EMU fan/pump/separator along with biological material. After this event the development of the ALCLR hardware aided in removing the free ionic material in the water originating from the Airlock and provided a periodic disinfection capability. Through periodic testing via water samples and examination of EMUs returned from orbit, it was determined that the ALCLR hardware was an effective mitigation to the EMU Feed-water contamination.

Current ALCLR Hardware Description

The ALCLR water processing kit was developed as a corrective action to EMU coolant loop flow disruptions experienced on the ISS in May 2004 and thereafter. 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. Periodic analysis of EMU coolant loop water and hardware examinations were used as a means to determine adequate functionality and optimized processing cycles as well as ALCLR component shelf life.

The ALCLR water processing kit (Figure 2) 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 Water Loop FPS. 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 inline to the EMU and 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.[4]

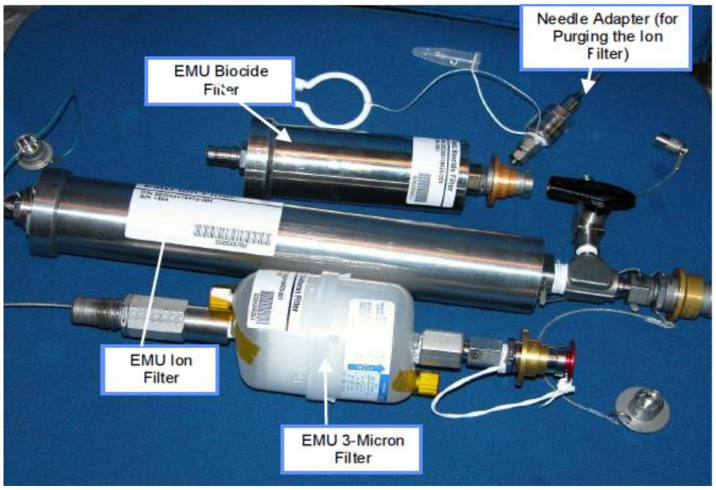


Figure 2. ALCLR processing kit components.

In service, a 3-micrometer 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 (Figure 3). After scrubbing with the EMU Ion Filter, the EMU Biocide Filter is installed to add residual iodine biocide for microbial control. The EMU Biocide Filter is a packed bed of ion exchange resin impregnated.[1,2,3,4]

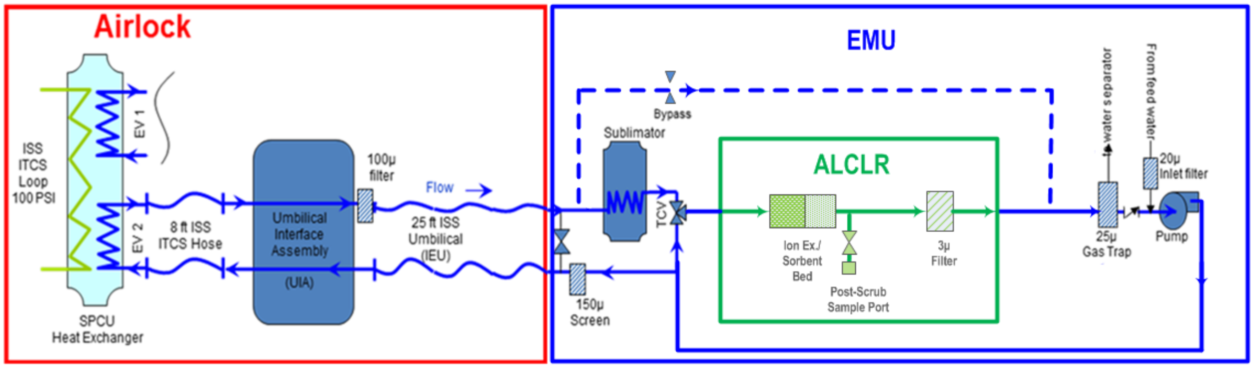


Figure 3. Current ALCLR In-line Configuration

Drivers and Overview of the ALCLR Redesign Effort

During EVA (Extravehicular Activity) 23 aboard the ISS (International Space Station) on 07/16/2013 water entered the EMU 3011(Extravehicular Mobility Unit) helmet resulting in the termination of the EVA shortly after it began. It was estimated that 1.5-L of water had migrated up the ventilation loop and into the helmet, adversely impacting the astronauts hearing, vision and verbal communication. Subsequent on-board testing and ground-based TT&E (Test, Tear-down and Evaluation) of the affected EMU hardware components led to the determination that the proximate cause of the mishap was blockage of all eight water separator drum holes with a mixture of silica and silicates. The blockages caused a failure of the water separator function which resulted in EMU cooling water spilling into the ventilation loop, around the circulating fan, and ultimately pushing into the helmet.

The root cause of the failure was determined to be ground-processing short-comings of the ALCLR (Airlock Cooling Loop Recovery) Ion Filter Beds which led to various levels of contaminants being introduced into the Filters before they left the ground. Those contaminants were thereafter inadvertently introduced into the EMU hardware on-orbit during ALCLR scrubbing operations. Simple means to analyze two parameters of the water in the EMU water cooling loop and the effluent from the ALCLR Ion Filter Beds could have prevented the mishap.

A Mishap Investigation Board was convened to investigate the mishap and an EVA Recovery Team was chartered thereafter to facilitate the return to nominal EVA capability on the ISS. Both teams recognized that the presence of an on-orbit means to evaluate the chemistry of the affected EMU water cooling loop and the contaminated ALCLR Ion Filter Beds could have led to the avoidance of this mishap.

Report recommendations from both teams address the on-orbit water monitoring issue as follows:

1) *Mishap Investigation Board, International Space Station Extravehicular Activity Suit Water Intrusion High Visibility Close Call, IRIS Case Number S-2013-199-00005, Dec. 20, 2013.*[5]

Recommendation #20: The ISS Program should *institute a systematic process of monitoring water quality and chemistry aboard ISS to track changes that can affect critical ISS systems including the EMU*, crew health, and multiple ISS Systems that use water and are sensitive to its chemical makeup. *This process should include consideration of onboard monitoring capability*. It should also include return of any removed hardware to the ground for evaluation.

2) *EVA Recovery Team Summary Report, EVA 23 Mishap Action Response, Root Cause Final Report, Nov.21, 2014.*[6]

Corrective Action #11: Develop a comprehensive suit water quality specification and water management plan to ensure that source water quality parameters that adversely affect suit operation are understood, controlled and verified at all facilities that process EMU hardware. *This should include a strategy for on-orbit water system health insight and monitoring* including on-orbit acceptability limits.

The MIB and ERT recommendations related to the EVA 23 mishap were key drivers to the ALCLR redesign effort. A primary goal of the redesign effort is to select and integrate an in—line conductivity sensor which would dwell in the effluent stream of the ALCLR Ion Filter during scrubbing operations to identify, real-time, if an Ion Filter break-through occurs due to an unanticipated contaminant load or an Ion Filter anomaly. Identification, development and integration of an in-line or off-line pH measurement capability is also included in the redesign effort to allow the measurement of effluent pH, given that large swings in effluent pH can occur if an ion exchange bed were to break-through.

Additional findings from the EVA 23 investigation included shortcomings of the current ALCLR Ion Filter. The activated carbon currently utilized in the design is lignite-based, and an inherent source of low-level contaminants (ionic and particulate) to the downstream Ion Filter ion exchange resin. It was recognized that commercially available synthetic carbon material offered equal or greater organic carbon scrubbing capacity while reducing the risk of ionic and particulate contamination to the downstream Ion Filter ion exchange resin. Identification and testing of such a synthetic carbon is included as a goal in the ALCLR redesign effort.

Furthermore, it was recognized that the ion exchange resin currently used in the ALCLR Ion Filter is “separable” by design, meaning that purposeful differences in resin size and density allow for in-line resin regeneration in ground applications. This offers no advantage to the EMU application and in fact, represents a risk. “Separable” ion exchange resin poses a risk with relatively small ion exchange resin beds due to the potential of a resultant packed bed with an excess of anion or cation exchange resin at the effluent side of the bed. Such an outcome can lead to large shifts in effluent pH near the end-of-life of the Ion Filter, and subsequent adverse impact on downstream wetted materials. That became a driver for the identification of a “non-separable” ion exchange resin as part of the ALCLR redesign effort.

Additionally, it was recognized that the 50:50 by volume activated carbon / ion exchange resin mix (a carryover from the prior ACTEX application) was not optimal for the EMU application. A need to optimize the life of the Ion Filter via an activated carbon/ion exchange resin tailored to the EMU contaminant challenge is therefore included as a goal of the ALCLR redesign as well..

Finally, the in-line monitoring of conductivity and the in-line or off-line measurement of pH requires a great deal of design effort to maximize the benefits of the enhanced capabilities, while minimizing weight, power, logistics and crew touch-time impacts. The overall design effort is detailed in this paper.

Design Changes to the ALCLR

The MIB and ERT recommendations for changes to the ALCLR system that would reduce the greatest amount of risk to the EMU were approved for implementation. These changes included an in-line conductivity sensor, pH measurement in the case of an EMU Bed breakthrough identified by the in-line conductivity sensor, an ALCLR bypass valve and an upstream sample port. The updated ALCLR in-line configuration is shown in Figure 4.

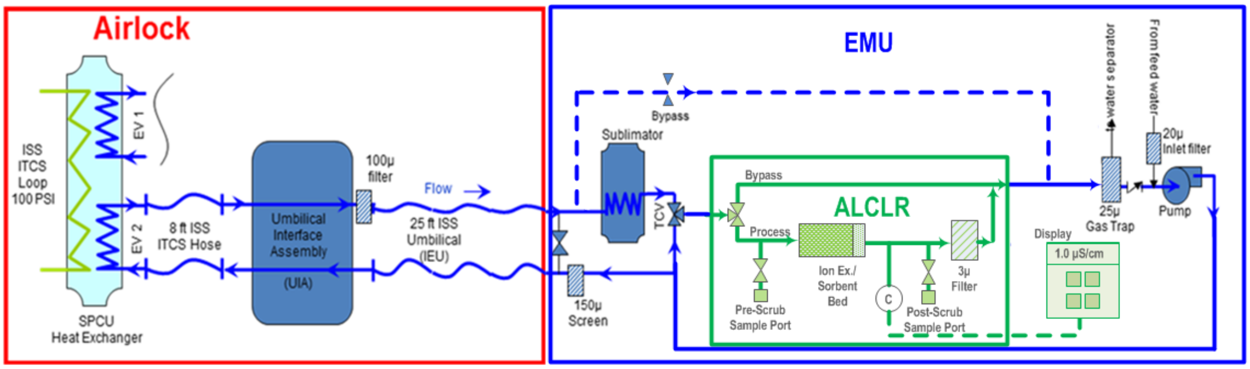


Figure 4. Redesign of the ALCLR In-line Configuration

A hand-held conductivity meter has been implemented on-orbit for analyzing post-scrub samples for conductivity. However, samples have not always been analyzed in a timely manner. Occasionally samples have had time to absorb CO_2 into the sample, altering the conductivity results. Also, the handheld conductivity meter was rinsed with Potable Water Dispenser (PWD) water, which was (at times) higher in conductivity than the sample being analyzed.

An in-line conductivity sensor will be implemented downstream of the EMU Ion Filter to monitor the conductivity of effluent water from the EMU Ion Filter real-time, to determine if the Ion Filter ion exchange resin has reached the exhaustion point, or if the EMU Ion Filter is performing off-nominal for some other reason. A conductivity threshold will be set, and once this conductivity threshold is exceeded, the conductivity sensor shall send a signal to a digital display which will include a light to notify the crew to take action. Actions can be taken real time to remediate poor water quality and reduce risk to the hardware and to the crewmembers.

The EMU Ion exchange filter currently has a downstream sample port integrated into the outlet of the housing. However, there is no method of taking a sample of the EMU transport loop water upstream of the EMU Ion Exchange Filter if needed. A sample port will be added upstream of the EMU Ion exchange filter identical to the one integrated into the outlet of the housing. This upstream sample port will allow for drawing a sample of the pre-scrub sample water, which will provide insight into the current health of the EMU transport loop water.

A bypass valve will be added to allow the astronaut to replace the IX Exchange/Sorbent Filter, the 3-Micron Filter, or the EMU Biocide Filter while the EMU pump is still running. The bypass valve will be a 3/8” three-way hand valve. Changing filters while the EMU is running will reduce the number of fan cycles on the EMU. Reducing the number of fan cycles is desirable because excessive fan cycles allows for more moisture in the F/P/S, promoting corrosion.

A)Operational Scenario

The operational scenario of the re-designed EMU ALCLR assembly starts with the beginning of an EVA series. An EVA series can be 1 to 6 EVAs with less than or equal to 2 weeks between EVAs and a maximum time between first and last EVA of 8 weeks. To remove any contaminants that may have formed during EMU/Airlock down time, both EMU/Airlock coolant loops, and EMUs planned for use in the upcoming series of EVAs will be scrubbed using the ALCLR Ion Filter and 3-micron filter in series. This scrub will occur within four weeks prior to the suits being used for that series of EVAs.

No more than two weeks after that series of EVAs, the EMU/Airlock coolant loops and EMUs used need to be scrubbed with the ALCLR Ion Filter and 3-micron filter in series (see Figure 5) to remove all contaminants that were formed during the EVA series. This ensures that the gas trap and pump area are not left with contaminants that may form precipitates that could adversely impact functionality.

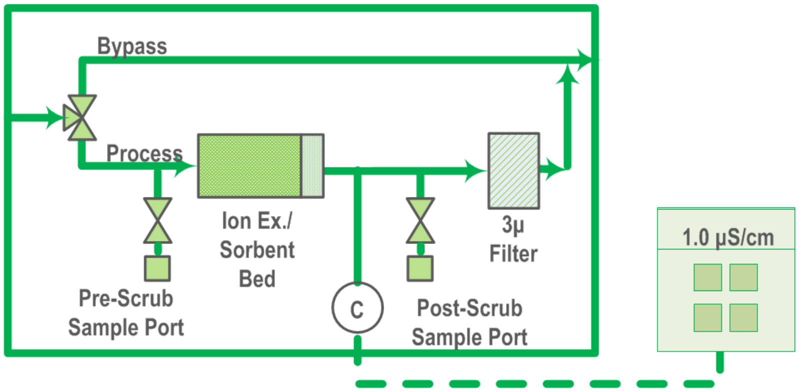


Figure 5. ALCLR in Scrub Configuration

After completion of the cooling loop scrub, the Ion Filter is iodinated for a brief period of time by placing the Biocide filter upstream of the Ion Filter and flowing for 15 seconds. This serves to reduce the microbial population before storage of the Ion Exchange/Sorbent bed (see Figure 6).

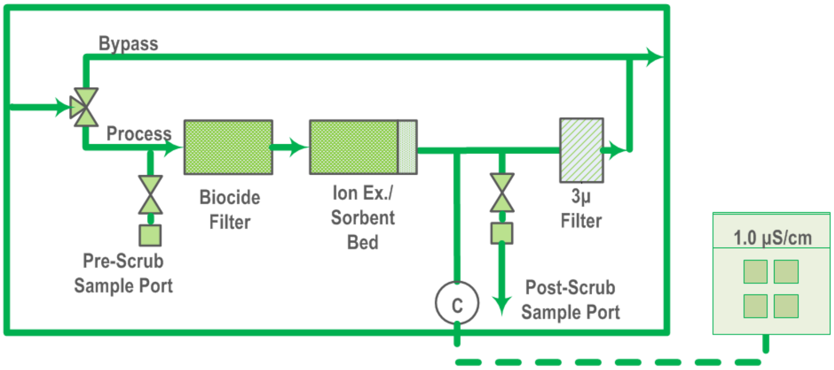


Figure 6. ALCLR in Ion Filter Iodination Configuration

After the suits and loops are scrubbed, they will be iodinated (see Figure 7) using the Microbial Check Valve (MCV) to provide a residual biocide for microbial growth control. If the EMUs, wetted LCVGs or heat exchanger and airlock coolant loops are not used for more than 90 days, the EMU, LCVG, heat exchanger and airlock coolant loops shall be scrubbed and iodinated.

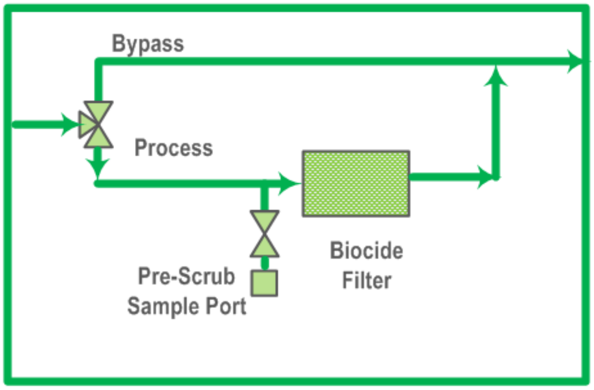


Figure 7. ALCLR in Scrubbing Configuration

B) Design Effort Status

The ALCLR bypass valve and upstream sample port are fabricated from commercial off-the shelf (COTS) parts. The upstream sample port will be identical to the existing downstream sample port. A 3-way ball valve was selected as the ALCLR bypass valve. A trade study was performed to select the best methods of conductivity and pH measurement methods. A commercially available conductivity sensor and display were chosen for conductivity measurement. The conductivity display will be mounted on the ISS Airlock wall with Velcro tape. A custom power cable will be designed to provide 28 VDC to the conductivity sensor and display from the ISS Airlock Power Supply Assembly (PSA). However, the best method of measuring pH was found to be commercial pH test strips. A pH sample bag assembly will be developed for the ALCLR similar to one currently in use on-orbit the ISS for OPA and ammonia analysis in IATCS coolant water.

C) Certification Plans

It is expected that the redesigned ALCLR will have 2-N classification, the same as its current classification. Components of the new ALCLR Redesign build that are the same as the current design will be certified by similarity to the current design. None of the components in the current design or in the redesign are considered fracture critical. COTS components (fittings, valves) will be used wherever possible for new items; these items may not meet ISS requirements and will be certified following the COTS certification approach documented in SSP 50986. COTS components will not be required to meet EEE parts requirements, but it is expected that the EEE parts certification will not be performed. Grade 4 components are likely to be used. It is planned that an electrical stress analysis, thermal analysis, Non-Standard Parts Approval Request (NSPARs) or a radiation analysis will not be performed for the COTS hardware. The conductivity/pH sensors and the display/data logger may be susceptible to Single Event Upset/Single Event Latch-up/Single Event Burnout (SEU/SEL/SEB). It is expected that the pH test kit will require only materials certification.

Conductivity and pH Measurement Evaluation

Efforts were undertaken to evaluate COTS in-line and off-line means to measure conductivity and pH for the ALCLR redesign effort. The intent of the conductivity sensor is to determine real-time if an ALCLR Ion Filter is not functioning correctly (contaminated or exceeded capacity). Once a conductivity offset indicated that an ALCLR Ion Filter was not functioning correctly, the user would shut off the EMU Pump to halt the water scrubbing step. The conductivity sensor, therefore, needs to be in-line to be a real-time warning of inadequate scrubbing performance. When an EMU Ion Filter has exceeded scrubbing capacity, the effluent from the can undergo significant shifts in pH, depending on whether there is an excess of anion exchange resin capacity (basic effluent) or excess cation exchange resin capacity (acidic pH). That phenomena has been demonstrated in the UTAS WL Laboratory and is shown in Figure 8. The intent of the pH measurement, therefore, is to determine if immediate remedial action needs to be taken to flush and EMU Transport Water Loop after an Ion Filter break-through. If the effluent pH were to be determined to be “3” for instance, the corrosion risk to EMU wetted materials in the Transport Water Loop would be high, and immediate neutral water flushing would be recommended. If, on the other hand, the pH of the effluent was determined to be “6”, for instance, an immediate neutral water flush would not be necessary and the user could likely wait until the next scheduled ALCLR operation.

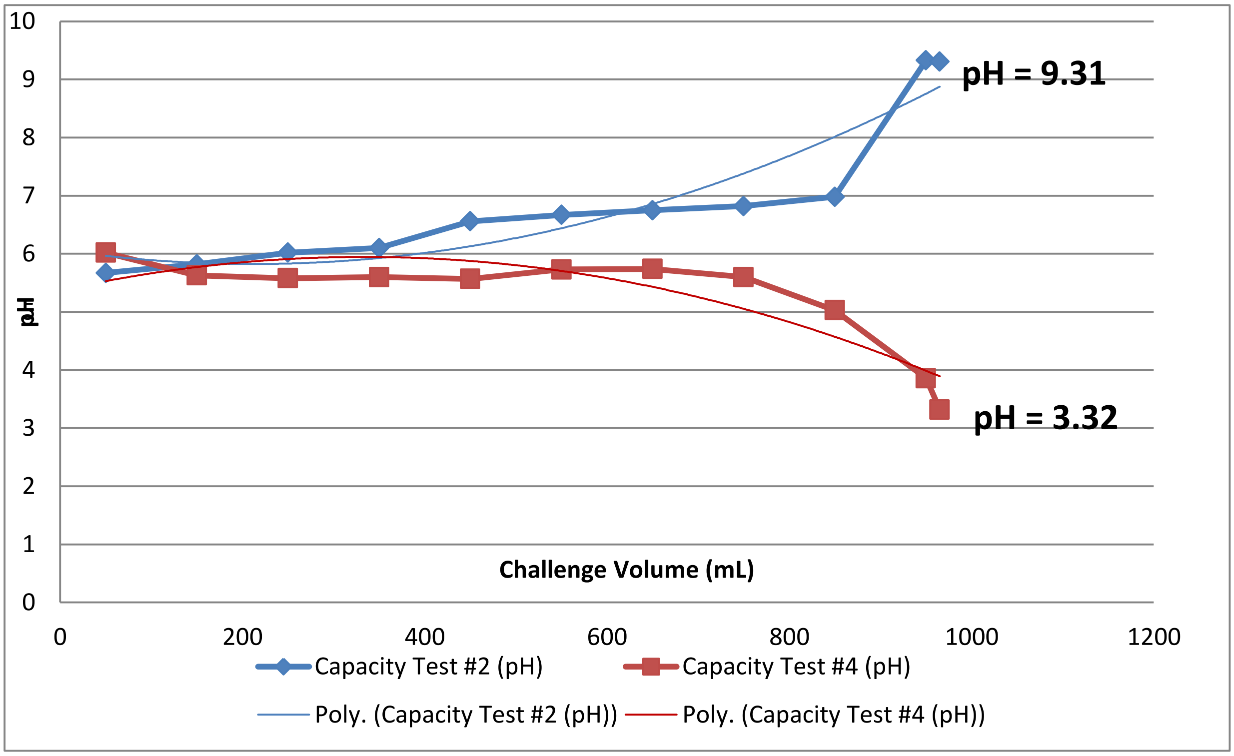


Figure 8. Ion Filter Effluent pH at Break-through Point

Conductivity Measurement

The determination of the conductivity in water is a measurement of its ability to conduct electricity. Conductivity measurements are used routinely in many industrial and environmental applications as a fast, inexpensive and reliable way of measuring the ionic content. The in-line conductivity measurement of the effluent from an ion exchange resin bed such as the ALCLR Ion Filter is a direct means to determine the health of the Ion Filter and the success of a scrub operation.

Two types on in-line conductivity sensors are commonly available commercially. The first, referred to as a Contacting Conductivity Sensor, consists of two metal electrodes in contact with the water stream. The analyzer applies an alternating voltage to the electrodes. An electric field causes the ions to move back and forth, producing a current. The analyzer measures the current. The second, referred to as an Inductive, Toroidal or Electrodeless Sensor, consists of two wire-wound torids encased in a plastic body. One torid serves as the “drive” coil, while the other acts as the “receive” coil. The analyzer applies an alternating voltage to the drive coil which induces a voltage in the water surrounding the coil. The voltage causes an ionic current to flow proportional to the conductance of the water. The ionic current induces an electric current in the receive coil, which the analyzer measures.

Four different in-line conductivity sensors with their corresponding controllers are in the process of being evaluated as part of this study. Table 1 provides details on the in-line conductivity sensors being evaluated for this application.

Company	Sensor Type	Sensor Model/Part Number	Sensor Controller Model/Part Number
Advanced Sensor Technologies	In-line Contacting	AST51-0,1-1000-10-TL ½-inch	3TX-3MF-3TX-CON-L-0.1/0.2
Hach	In-line Contacting	3422A1A	Sc200-LXV404.99.50222
Foxboro	In-line Contacting	871CR-A2T1B1A-S	876CR
Foxboro	In-line Electrodeless	871EC-UTO/EP397N	876EC

Table 1. Candidate Conductivity Sensors

A set of selection criteria was established to evaluate the adequacy of an in-line conductivity for the ALCLR re-design application (see Table 2). Ratings against these criteria, ranging from -2 to +2 (see Table 3) formed the basis for a regimented scoring to allow a comparison between sensors. The criteria were assigned weighing factors based on a team-established assessment of the criteria against application needs (not shown in this publication).

Criteria	Target		Criteria	Target
Operational Mode	In-line		EMI Certification	EMI Data Available
Integration	Ease of - into filter assembly		Warning/Off-nominal Indicators	Threshold breach warning
Measurement Range	1.0 – 50 uS/cm (ideal)		Robustness of Design	Access Survivability
Recovery from Upset	< 5.0 min. with water flow		Data Logging	Ability to Store and Access Data
Measurement Time	< 5.0-sec.		Flowrate Limit	60-lb/hr. Optimal
Accuracy / Precision	+/- 5%		Long-term Effects of Moisture Contact	Minimal
Calibration	> once every 2-years		Ease of Use by Crew	Ease of Operation
Maintenance	> once every 2-years		Cost	Lower Cost Preferred
Component Life	> 6-years		Lead-time for Receipt	Short Time Preferred
Electrical (voltage)	Adaptability to 28 VDC		Flow Orientation vs Package Complexity	For Sensor Only Want to Reduce
Electrical (max current draw)	Low (TBD)		Ease of Certification as COTS	Lack of Needs for Mod
Electrical (data handling)	Simplicity (analog design best)		Supplier Quality Control	Supplier in the QASL
NASA Heritage	NASA Use of Technology		120 VAC Compatibility	Option, Not Optimal

Table 2. Conductivity Measurement Approach Selection Criteria

Rating Values	Description
-2	Performs significantly worse than the reference sensor
-1	Inferior to the reference sensor
0	Equal to the reference sensor
1	Superior to reference sensor
2	Performs significantly better than the reference sensor

Table 3. Ratings Applied to Conductivity Measurement Approach Selection Criteria

For the weighing factor determinations, each criterion was rated against all others individually as to which was more important for the application. The number of times that a criterion was determined to be more important than another was summed up. The sum of the number of times that a criterion was judged to be more important than another was divided by the total number of comparisons (322 in this case). The total number of comparisons (322) was normalized to 100 (100/322) to determine a multiplier (0.31). The multiplier (0.31) multiplied by the number of times a criterion was cited as more important than another yields the weighing factor that was applied.

Each in-line conductivity sensor was tested with known conductivity standards made up with KCl (potassium chloride) per CRC handbook directions.[9] An initial baseline with deionized water was then established with each sensor. Sequentially, each standard that was verified with an independent, calibrated laboratory conductivity sensor was exposed to each sensor until a stable conductivity reading was observed. Conductivity reading stability time and final reading was then recorded. Finally, a deionized water baseline was re-established between each conductivity standard test. This process was repeated in triplicate. As a separate test, each conductivity sensor was challenged with known silicon standards to determine conductivity sensitivity to silica/silicic acid which is known to impart a weak conductivity increase in water.

<u>Hach In-line, Contacting Conductivity Sensor</u>

The Hach in-line conductivity sensor underwent conductivity standard challenges in a once-through flow scheme in triplicate. Sensor response to standards was almost immediate, limited only by the flow-rate of the standard between the feed reservoir and the sensor. The sensor returned to baseline with a deionized water flush almost immediately as well, limited only by the flow-rate of the deionized water between the feed reservoir and the sensor. Finally, recovery from an over-range conductivity standard (1.0 mM KCl at 140.8-microS/cm) was almost immediate, again limited only by the flow-rate of the standard between the feed reservoir and the sensor.

The performance data for the Hach in-line conductivity sensor was more than adequate for the EMU ALCLR re-design application as demonstrated by good repeatability, low standard deviations, and low percent differences between average conductivity readings and actual data determined by the independent, calibrated laboratory conductivity sensor (see Table 4). The Hach in-line conductivity sensor also easily picked up low ppm challenges with silica (source silica gel extract in water) as shown in Table 4. The rating values for the Hach In-line Conductivity Sensor are shown in Tables 5 and 6 as an example only. For brevity, this data is not shown for the other evaluated sensors and measurement approaches. The total weighted rating score for the Hach In-line Conductivity Sensor after weighing factors were applied was + 44.1 at the time of this writing, with several ratings still pending.

Hach Model SC200 Contacting Conductivity Sensor

		KCl Conductivity Standards							
Concentration of KCl	**Benchtop Conductivity (uS/cm)**	**#1**	**#2**	**#3**	**Average**	**Standard Deviation**	**%RSD**	**Deviation of Average from Benchtop**	**% Difference**
0.01 mM	0.72	0.70	0.70	0.71	0.70	0.01	0.82	-0.02	-2.31
0.1 mM	15.1	14.3	14.3	14.5	14.4	0.12	0.80	-0.73	-4.86
0.5 mM	72.4	68.9	69.0	69.4	69.1	0.26	0.38	-3.30	-4.56
1.0 mM	140.8	**Over Range**							

		Silicon Challenge
Silcon Concentration from Silica Gel (ppm)	**Benchtop Conductivity (uS/cm)**	
6.7	4.8	4.95
20	8.8	8.68

Notes:
Sensor response was <30 seconds, limited only by the volume of tubing between feed and sensor.
Sensor return to baseline was <30 seconds, limited only by the amount of DI water needed to flush tubing.
Recovery from over-range (1.0 mM KCl) was <30 seconds, limited only by the amount of DI water needed to flush tubing.

Table 4. Performance Results for Hach In-line Conductivity Sensor

Criteria	**Target**	**Finding**	**Rating Value**
Integration	Ease of - into filter assembly		0
Measurement Range	1.0 – 50 uS/cm (ideal)	0.72 – 72.4 uS/cm	+1
Recovery from Upset	< 5.0 min. with water flow	<< 30-sec (essentially immediate)	+2
Measurement Time	< 5.0-sec.	<< 5.0-sec (essentially immediate)	+2
Accuracy / Precision	+/- 5%	2.31% - 4.86% within in the operational range of 0.72 – 72.4 uS/cm	0
Calibration	> once every 2-years	Quarterly or slope change; much less with high purity water	-1
Maintenance	> once every 2-years	Quarterly or slope change; much less with high purity water	-1
Component Life	> 6-years	Up to 10-years field experience	+2
Electrical (voltage)	Adaptability to 28 VDC	Tested model not compatible with 28VDC	-2
Electrical (max current draw)	Low (TBD)	Current draw is less than 0.2A; PSA max out = 6A	+2
Electrical (data handling)	Simplicity (analog design best)		
NASA Heritage	NASA Use of Technology	No	0
EMI Certification	EMI Data Available	EMC: CE compliant for conducted and radiated emissions. CISPR 11 (Class A limits), EMC Immunity (EN61326-1 (Industrial limits) Must compare to requirements	-1

Table 5. Rating Values for Hach In-line Conductivity Sensor – Part 1

Criteria	**Target**	**Finding**	**Rating Value**
Warning/Off-nominal Indicators	Threshold breach warning	No red light or audible. Four relays available for external user-supplied warning	-1
Robustness of Design	Access Survivability	Adequate	0
Data Logging	Ability to Store and Access Data	Yes – 128K memory. Could store 18,000 data points SD card slot to transfer files to a computer	+1
Flowrate Limit	60-lb/hr. Optimal	Essentially none. 60-lb/hr. tested and performed well	0
Long-term Effects of Moisture Contact	Minimal	None known for sensor head. Designed for continuous submersion	0
Ease of Use by Crew	Ease of Operation	Very user friendly once plumbed	+2
Cost	Lower Cost Preferred	Sensor = $522; Controller $1,266	0
Lead-time for Receipt	Short Time Preferred	TBD	TBD
Flow Orientation vs Package Complexity	For Sensor Only Want to Reduce	Sensor is of average complexity to integrate and nominal flow orientation	0
Ease of Certification as COTS	Lack of Needs for Mod	No modifications required	0
Supplier Quality Control	Supplier in on QASL		
120 VAC Compatibility	Option, Not Optimal	This controller was tested with 120VAC power	+2

Table 6. Rating Values for Hach In-line Conductivity Sensor – Part 2

Foxboro In-line Contacting Conductivity Sensor

The Foxboro in-line contacting conductivity sensor underwent conductivity standard challenges in a once-through flow scheme in triplicate (see Figure 9). Sensor response to standards was almost immediate, limited only by the flow-rate of the standard between the feed reservoir and the sensor. The sensor returned to baseline with a deionized water flush almost immediately as well, limited only by the flow-rate of the deionized water between the feed reservoir and the sensor. Finally, recovery from an over-range conductivity standard (1.0 mM KCl at 140.8-microS/cm) was almost immediate, again limited only by the flow-rate of the standard between the feed reservoir and the sensor.

The performance data for the Foxboro in-line contacting conductivity sensor was more than adequate for the EMU ALCLR re-design application as demonstrated by good repeatability, low standard deviations, and low percent differences between average conductivity readings and actual data determined by the independent, calibrated laboratory conductivity sensor. (Table 7) The Hach in-line conductivity sensor also easily picked up low ppm challenges with silica (source silica gel extract in water) as shown in Table 7. Finally, The Foxboro in-line contacting conductivity sensor can be powered with the existing ISS/EMU power source of 28 VDC. The total weighted rating score for the Foxboro In-line Contacting Conductivity Sensor after weighing factors were applied was +76.1 at the time of this writing, with several ratings still pending.

	KCl Conductivity Standards								
Concentration of KCl	Benchtop Conductivity (uS/cm)	#1	#2	#3	Average	Standard Deviation	%RSD	Deviation of Average from Benchtop	% Difference
0.01 mM	0.70	0.66	0.69	0.72	0.69	0.03	4.35	-0.01	-1.43
0.1 mM	14.68	14.6	14.8	14.6	14.7	0.09	0.60	-0.03	-0.20
0.5 mM	69.9	73.0	68.7	72.4	71.4	2.32	3.24	1.45	2.07
1.0 mM	140.5	141.5	140.2	139.9	140.5	0.85	0.61	0.03	0.02

	Silicon Challenge								
Silcon Concentration from Silica Gel (ppm)	Benchtop Conductivity (uS/cm)	#1	#2	#3	Average	Standard Deviation	%RSD	Deviation of Average from Benchtop	% Difference
2.28	2.59	2.74	2.72	2.65	2.70	0.05	1.75	0.11	4.38
10.8	6.74	7.05	7.02	6.99	7.02	0.03	0.43	0.28	4.15

Table 7. Performance Results for Hach In-line Conductivity Sensor

Summary of Total Weighted Rating Scores for Conductivity Sensor and Measurement Approaches

The to-date results of the total weighted rating scores for two of the four methods to measure conductivity are summarized in Table 8. Two date results indicated that the Foxboro In-line contacting, conductivity sensor is the best match for this application

Measurement Approach	Total Weighted Average
Hach In-line Contacting	+41.1
Foxboro In-line Contacting	+76.1
Foxboro In-line Electrodeless	pending
AST In-line Contacting	pending

Table 8. Summary of Total Weighted Rating Scores – Conductivity Sensors & Measurement Approaches

pH Measurement

The determination of pH in water is a measure on the hydrogen ion concentration and is a measure of the acidity or basic nature of a water sample. Water samples at 25 C^{o} with a pH less than 7 are acidic, while those with a pH greater than 7 are basic. Water with significant acid or base pH character can severely attack wetted materials of construction, particularly metals. When an ALCLR Ion Filter becomes exhausted, rapid shifts in the effluent water pH are possible (see Figure 8), and that can drive a need for immediate on-orbit remediation action such as copious flushing. It should be noted that if a ALCLR Ion Filter were to become exhausted, that would be picked up with the targeted in-line conductivity sensor previously described. The EMU pump would be immediately turned off at that point. The measurement of pH occurs after that occurs to assess potential risk to the EMU hardware and that measurement can either be taken in-line of off-line.

Two types on in-line pH sensors are commonly available commercially. The first, referred to as a porous glass electrode, consists of two electrodes submerged in the water stream or sample. Ion swapping occurs between hydrogen ions in solution and metal ions from the glass electrode. Hydrogen ion activity occurs on the surface of the electrode which causes an electric charge to build up. A resultant charge difference on the two sides of the glass electrode leads to a voltage difference on the two sides of the glass electrode. The difference in voltage between the glass electrode and a reference electrode shows up as a pH measurement value on a meter thereafter. The second, referred to as an ISFET (Ion Selective Field Effect Transition) involves hydrogen ions in solution accumulating onto a gate electrode proportional to the pH of the water sample and/or stream. The positive charge of the hydrogen cations influences the current between source and drain components in the electrode. The pH changes equate to variances in accumulated hydrogen ions which causes current through a transition to change. A reference electrode maintains a drain-source current at a constant value which essentially serves as a reference.

Additionally, an ISFET-based portable off-line pH sensor is also commercially available. It functions in a similar matter to the previously described in-Line ISFET based pH sensor.

Finally, pH test strips, which are essentially pieces of paper with deposited pH indicators that change color depending on the pH of a drawn water sample are available. The pH indicators used for this application are generally weak acids or weak bases that change color at specific pH levels.

Two in-line pH sensors with their corresponding controllers (one glass-probe-based, the other ISFET-based) were evaluated as part of this effort. Furthermore, one off-line ISFET-based sensor was evaluated as part of this study. Finally, wide-range pH test strips that would be integrated into a Teflon bag in the same matter as the current ISS IATCS ammonia and OPA test strips, and would be used off-line in this application, were evaluated. Table 9 provides details on the pH measurement equipment evaluated in this study.

Company	Sensor / Method Type	Sensor / Method Model/Part Number	Sensor / Method Controller Model/Part Number
Honeywell	In-line Glass Probe	P/N 07777-0-18-0000-000	P/N APT2000PH-H-IS-E00
Honeywell	In-line ISFET	P/N 07777DVP-03-04-0000-000	P/N APT2000PH-H-IS-E00
Hach	Off-line ISFET	Model H135	N/A
EDM Millipore	Off-line Integrated into Teflon Bag	Part Number 109535 Universal (pH 1 – 14)	N/A

Table 9. Candidate pH Measurement Approaches

A set of selection criteria was established to evaluate the adequacy on the in-line and off-line pH measurement approaches for the ALCLR re-design application (see Table 10). Ratings against these criteria, ranging from -2 to +2 (see Table 3) formed the basis for a regimented scoring to allow a comparison between sensors. The criteria were assigned weighing factors based on a team-established assessment of the criteria against application needs (not shown in this publication).

For the weighing factor determinations, each criterion was rated against all others individually as to which was more important for the application. The number of times that a criterion was determined to be more important than another was summed up. The sum of the number of times that a criterion was judged to be more important than another was divided by the total number of comparisons (322 in this case). The total number of comparisons (322) was normalized to 100 (100/322) to determine a multiplier (0.31). The multiplier (0.31) multiplied by the number of times a criterion was cited as more important than another yields the weighing factor that was applied.

Each in-line and off-line pH sensor was tested with known pH buffer solutions acquired commercially or made up per DeLloyds Laboratory Resources.[10] An initial baseline with deionized water was then established with in-line sensor. Sequentially, each buffer was exposed to each measurement approach. The pH reading stability time and final reading was then recorded. Finally, a deionized water baseline was re-established between each in-line pH buffer test. This process was repeated in triplicate.

Criteria	Target		Criteria	Target
Operational Mode	In-line		EMI Certification	EMI Data Available
Integration	Ease of - into filter assembly		Warning/Off-nominal Indicators	Threshold breach warning
Measurement Range	1 - 14		Robustness of Design	Access Survivability
Recovery from Upset	< 5.0 min. with water flow		Data Logging	Ability to Store and Access Data
Measurement Time	< 5.0-sec.		Flowrate Limit	60-lb/hr. Optimal
Accuracy / Precision	± 1 pH Unit		Long-term Effects of Moisture Contact	Minimal
Calibration	> once every 2-years		Ease of Use by Crew	Ease of Operation
Maintenance	> once every 2-years		Cost	Lower Cost Preferred
Component Life	> 6-years		Lead-time for Receipt	Short Time Preferred
Electrical (voltage)	Adaptability to 28 VDC		Flow Orientation vs Package Complexity	For Sensor Only Want to Reduce
Electrical (max current draw)	Low (TBD)		Ease of Certification as COTS	Lack of Needs for Mod
Electrical (data handling)	Simplicity (analog design best)		Supplier Quality Control	Supplier in the QASL
NASA Heritage	NASA Use of Technology		120 VAC Compatibility	Option, Not Optimal

Table 10. pH Measurement Approach Selection Criteria

EDM Millipore pH Test Strips

The EDM Millipore pH Test Strips were testing with five independent users Buffers 1, 3, 11 and 13 were prepared per DeLloyd's Laboratory Resources.[10] Buffers 1A (a repeat of the test run with a buffer made up per DeLloyd's Laboratory Resources), 4, 7 and 10 were purchased commercially. The mode (value identified the most out of the five independent users) was correct 100% of the time. In no case was an incorrect response greater that 1 pH unit more than the buffer standards (see Table 11). The pH test strips provided significant advantage in several key areas. There are no power needs, no anticipated EMI challenges, long shelf-life (up to 5-years), no need for calibration, simplicity in design, and existing means to implement (same as is used with the current ISS IATCS ammonia and OPA test strips) to name a few (see Figure 9) The total weighted rating score for the EDM Millipore pH Test Strips after weighing factors were applied was + 99.7 at the time of this writing, with several ratings still pending.

pH Test Strips

Buffer Label	Target pH	Actual pH	#1	#2	#3	#4	#5	Mode	Number of Incorrect Responses	Maximum Number of Units from Correct Answer
A	10	9.95	10	10	11	10	10	10	1	1
B	3	2.92	3	3	3	3	3	3	0	0
C	1	0.91	1	0	1	0	1	1	2	1
D	7	6.99	7	7	6	7	7	7	1	1
E	4	4.01	4	4	4	4	4	4	0	0
F	11	10.88	11	10	11	12	11	11	2	1
G	13	12.96	13	14	13	13	14	13	2	1
H	1(A)	1.00	1	1	1	1	1	1	0	0

Table 11. Performance Results for EDM Millipore pH Test Strips

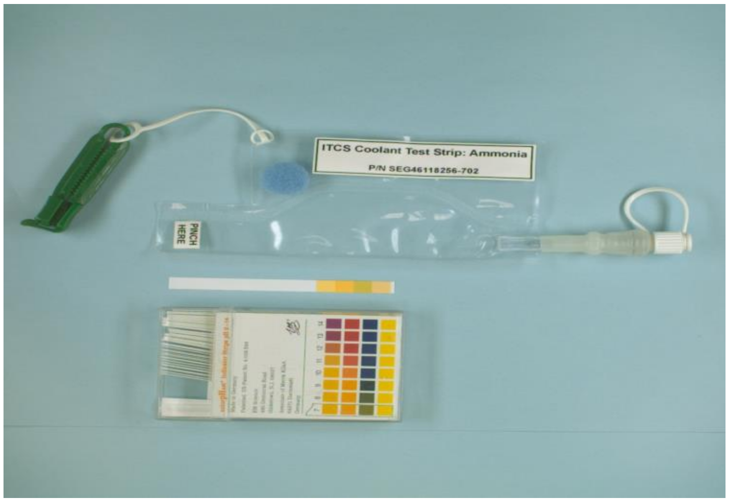


Figure 9. pH Test Strip With Teflon Bag Assembly & Color Chart

Hach Hand-Held ISFET Based pH Meter

The Hach Hand-Held ISFET Based pH Meter was tested in triplicate with the known pH buffer solutions used for the EDM Millipore Test Strips. (see Table 12). There was generally poor performance observed in the pH 1 – 4 range. Furthermore, this sensor was found to be very sensitive to rinsing and drying between measurements. Additionally, it was found that the ISFET electrode was easily detached from the body. Finally, input from the supplier indicated a need to frequent re-calibration. The total weighted rating score for the Hach Hand-Held ISFET based pH Meter after weighing factors were applied was – 15.2 at the time of this writing, with several ratings still pending.

		Droplet Technique								
Buffer Target	**Actual pH**	**#1**	**#2**	**#3**	**#4**	**Average**	**Standard Deviation**	**%RSD**	**Deviation of Average from True (pH units)**	**% Difference**
1	0.87	0.6	0.7	0.5	0.3	0.5	0.2	32.5	-0.3	-39.7
3	2.91	2.3	2.5	2.5	2.6	2.5	0.1	5.1	-0.4	-14.9
4	4.01	3.6	3.6	3.8	3.8	3.7	0.1	3.1	-0.3	-7.7
7	6.98	7.0	7.2	6.9	7.2	7.1	0.2	2.1	0.1	1.4
10	9.94	10.7	10.9	10.8	10.8	10.8	0.1	0.8	0.9	8.7
11	10.89	11.1	11.3	11.3	11.2	11.2	0.1	0.9	0.3	3.1
13	12.97	12.9	13.1	13.0	13.4	13.1	0.2	1.6	0.1	1.0

		Submerge Technique								
Buffer Target	**Actual pH**	**#1**	**#2**	**#3**	**#4**	**Average**	**Standard Deviation**	**%RSD**	**Deviation of Average from True (pH units)**	**% Difference**
1	0.87	0.5	0.7	0.5	0.4	0.5	0.1	24.0	-0.3	-39.7
3	2.91	2.3	2.3	2.3	2.5	2.4	0.1	4.3	-0.6	-19.2
4	4.01	3.6	3.6	3.5	3.8	3.6	0.1	3.5	-0.4	-9.6
7	6.98	7.0	7.1	6.9	7.2	7.1	0.1	1.8	0.1	1.0
10	9.94	10.7	10.8	10.7	10.8	10.8	0.1	0.5	0.8	8.1
11	10.89	10.5	11.3	11.1	11.5	11.1	0.4	3.9	0.2	1.9
13	12.97	12.9	12.8	13.0	13.5	13.1	0.3	2.4	0.1	0.6

Table 12. Performance Results for the Hach Hand-held ISFET Based pH Meter

Honeywell In-Line Glass Probe pH Sensor

The Honeywell Glass Probe pH Sensor was tested in triplicate with the known pH buffer solutions used for the EDM Millipore Test Strips. It was tested in both in-line and off-line configurations (see Tables 13 and 14). There was generally marginal performance observed in the pH 1 – 3 range with the in-line and off-line configurations. Also, measurement time was a bit sluggish. Power was necessary for the controller and the possibility of designing a AC to DC inverter existed. Additionally, supplier input indicated a need for frequent calibration that may need to occur once per month to once per quarter. Another shortcoming was that the glass probe itself was considered to be generally non-robust. Per supplier input, there is a maintenance need of a change out of a reference electrode approximately every 2-years. Finally, the in-line measurements were generally noisy in the 60-lbs/hr flowrate range. The total weighted rating score for the Honeywell Glass Probe pH Sensor after weighing factors were applied was –1.9 at the time of this writing, with several ratings still pending.

		In-Line Technique Test #1						
Buffer Target	**Actual pH**	**#1**	**#2**	**Average**	**Standard Deviation**	**%RSD**	**Deviation of Average from True (pH units)**	**% Difference**
1	0.92	1.11	1.05	1.08	0.04	3.93	0.16	17.4
3	3.12	3.05	3.08	3.07	0.02	0.69	0.06	1.8
4	3.95	3.87	3.91	3.89	0.03	0.73	0.06	1.5
6	5.95	5.93	5.97	5.95	0.03	0.48	0.00	0.0
10	9.97	10.18	10.15	10.17	0.02	0.21	0.19	2.0
11	10.89	11.14	11.15	11.15	0.01	0.06	0.25	2.3
13	13.02	13.02	13.07	13.05	0.04	0.27	0.03	0.2

Table 13. Performance Results for the Honeywell pH Meter With Glass Electrode – In-Line

Buffer Target	**Actual pH**	**#1**	**#2**	**#3**	**Average**	**Standard Deviation**	**%RSD**	**Deviation of Average from True (pH units)**	**% Difference**
1	0.94	0.95	0.86	0.83	0.88	0.06	7.1	0.06	6.38
3	3.15	3.01	2.99	3.00	3.00	0.01	0.3	0.15	4.76
4	3.96	3.87	3.87	3.85	3.86	0.01	0.3	0.10	2.44
6	5.95	6.07	5.97	5.97	6.00	0.06	1.0	0.05	0.90
10	9.93	10.21	10.20	10.16	10.19	0.03	0.3	0.26	2.62
11	10.76	11.04	11.08	11.10	11.07	0.03	0.3	0.31	2.91
13	12.94	13.06	13.07	13.26	13.13	0.11	0.9	0.19	1.47
4 - Certified Buffer	4.01	3.99	3.93	3.96	3.96	0.03	0.8	0.05	1.25
7 - Certified Buffer	7.00	7.11	7.11	7.10	7.11	0.01	0.1	0.11	1.52

Table 14. Performance Results for the Honeywell pH Meter With Glass Electrode – Off-Line

Honeywell In-Line ISFET pH Sensor

The Honeywell ISFET pH Sensor was tested in triplicate with the known pH buffer solutions used for the EDM Millipore Test Strips. It was tested in both in-line and off-line configurations (see Tables 15 and 16). There was poor performance observed in the pH 1 range with the in-line and off-line configurations. Power was necessary for the controller and the possibility of designing a AC to DC inverter existed Also, the supplier input indicated a need for frequent calibration that may need to occur once per month to once per quarter. Per supplier input, there is a maintenance need of a change out of a reference electrode approximately every 2-years. Finally, the sensor was found to be very sensitive to flow-rate and bubbles.. The total weighted rating score for the Honeywell Glass Probe pH Sensor after weighing factors were applied was – 1.9 at the time of this writing, with several ratings still pending.

Buffer Target	Actual pH	#1	#2	#3	Average	Standard Deviation	%RSD	Deviation of Average from True (pH units)	% Difference
1	0.9	1.18	1.24	1.20	1.21	0.03	2.53	0.31	34.1
3	3.11	3.18	3.19	3.17	3.18	0.01	0.31	0.07	2.3
4	3.94	3.98	3.94	3.97	3.96	0.02	0.53	0.02	0.6
6	5.89	5.98	5.98	5.96	5.97	0.01	0.19	0.08	1.4
10	9.97	10.20	10.21	10.21	10.21	0.01	0.06	0.24	2.4
11	10.86	11.09	11.34	11.45	11.29	0.18	1.63	0.43	4.0
13	13.01	13.13	12.95	13.01	13.03	0.09	0.70	0.02	0.2

Table 15. Performance Results for the Honeywell pH Meter With ISFET Electrode – In-Line

Buffer Target	Actual pH	#1	#2	#3	Average	Standard Deviation	%RSD	Deviation of Average from True (pH units)	% Difference
1	0.92	1.15	1.26	1.22	1.21	0.06	4.6	0.29	31.52
3	3.13	3.14	3.15	3.15	3.15	0.01	0.2	0.02	0.53
4	3.95	3.97	3.97	3.98	3.97	0.01	0.1	0.02	0.59
6	5.70	5.74	5.75	5.77	5.75	0.02	0.3	0.05	0.94
10	10.01	10.19	10.21	10.21	10.20	0.01	0.1	0.19	1.93
11	10.84	11.01	11.03	11.04	11.03	0.02	0.1	0.19	1.72
13	13.00	13.01	13.05	13.04	13.03	0.02	0.2	0.03	0.26
4 - Certified Buffer	4.01	4.06	4.05	4.06	4.06	0.01	0.1	0.05	1.16
7 - Certified Buffer	7.00	7.11	7.12	7.15	7.13	0.02	0.3	0.13	1.81

Table 16. Performance Results for the Honeywell pH Meter With ISFET Electrode – Off-Line

Summary of Total Weighted Rating Scores for pH Sensor and Measurement Approaches

The to-date results of the total weighted rating scores for the four methods to measure pH are summarized in Table 17. The pH test strip approach was the overwhelming winner, offering a number of advantages to the instrumental approaches. Since the ALCLR Redesign pH measurement approach can be in-line as well as off-line, the test strip approach was determine to be the path forward at the time of this writing.

Measurement Approach	Total Weighted Score
pH Test Strips	+99.7
Hach Hand-Held ISFET	-15.2
Honeywell In-line Glass Probe	-1.9
Honeywell In-line ISFET	-11.2

Table 17. Summary of Total Weighted Rating Scores – pH Sensors & Measurement Approaches

ALCLR Ion Filter Ion Exchange Resin, Activated Carbon and Ratio Thereof

Significant other findings from the EVA-23 Mishap Investigation and the aftermath were related to the ALCLR Ion Filter ion exchange resin and activated carbon. Three areas for improvement were identified.

First off, the current ion exchange resin used in the ALCLR Ion Filter (Purolite UCW-3600) is separable by design That is, the anion and cation exchange are segregated by size by the manufacturer so that the user can separate them via backflow for in-line generation. That feature is a disadvantage for a small packed ion filter such as that used in the ALCLR Ion Filter. Batch to batch variability has shown that certain lots contain anion and cation resin that separate rapidly and are at risk as segregating as a small ben is packed. If the effluent side of an ion exchange resin bed is too rich in anion exchange resin or cation exchange resin, the pH of the effluent can shift a great deal toward the basic pH range or acid pH range respectively. One aspect of the ALCLR redesign effort is to select and certify a non-separable mixed bed ion exchange resin to circumvent that risk. That effort had just begun at the time of this writing, but two promising, candidate non-separable, mixed bed ion exchange resins have been identified and efforts are underway to acquire samples for test.

Secondly, the activated carbon used in the ALCLR Ion Filter is lignite-based (Darco 20x40), which is inherently high in contaminants. A great deal of washing of this material must occur before it is used, and there appears to always be a low-level residual of contaminants. Since the activated carbon resides upstream from the ion exchange resin in the ALCLR Ion Filter, this low level contaminant load represents a low level challenge to the ion exchange resin which can deplete it more rapidly that necessary. At the time of this writing, a synthetic carbon (Ambersorb 4652) sample has been acquired for evaluation as a potential replacement for the Darco 20x40. An added advantage is that Ambersorb 4652 has gone through extensive testing by the NASA/Boeing community and has been certified for a ISS WPA MF bed application; specifically to replace the current activated carbon which has become obsolete. Furth more, water extract from the Ambersorb 4652 sorbent material underwent successful EMU mini-Sublimator testing as part of the UTAS support of the NASA/Boeing sorbent selection process. Again, hat effort had just begun at the time of this writing, but two promising, candidate non-separable, mixed bed ion exchange resins have been identified and efforts are underway to acquire samples for test.

Finally, the ratio of ion exchange resin to activated carbon in the ALCLR Ion Filter began as 50:50, which was inherited from the previous ACTEX application of this Ion Filter. This was never tailored to the EMU application. Testing will be conducted to validate that an ion exchange resin to activated carbon ration of 70:30 respectively would be more appropriate for the EMU application. No test results associated with this proposed change have been generated at the time of this writing.

Summary

The root cause investigation for the EVA-23 mishap identified several areas for improvement of the ALCLR Assembly and procedure which have since been initiated or are underway. Enhanced washing techniques for the ALCLR Ion Bed have been developed and implemented. Ground processing controls as well as controls for the quality of water used in hardware processing have been implemented.

An investigation into on-orbit cooling water conductivity and pH analysis capability to allow the astronauts to monitor proper operation of the ALCLR Ion Bed during scrubbing operation is underway. Conductivity via in-line contacting conductivity sensor looks promising and is being pursued. The measurement of pH via off-line pH test strip integrated into a Teflon bag, in the same fashion as is used for the on-orbit analysis of ISS IATCS coolant for ammonia and OPA concentration looks promising and is being pursued as well.

A design approach to integrate an in-line conductivity sensor has been presented and is being pursued. The implementation of a simple off-line means to determine EMU coolant water pH if an ALCLR Ion Filter became exhausted, resulting in an effluent pH shift, is being pursued. A simplified means to acquire on-orbit EMU cooling water samples is part of that design efforts as well.. Finally, an inherently cleaner organic adsorbent to replace the current lignite-based activated carbon, and a non-separable replacement for the separable mixed ion exchange resin are undergoing evaluation. These efforts are undertaken to enhance the performance and reduce the risk associated with ALCLR operations to ensure the long-term health of the EMU cooling water circuit.

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