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Analysis of Resin Samples From a Return-To-Ground Inlet Deionizing Bed for the ISS Oxygen Generation System

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Since 2007, the Oxygen Generation System (OGS) on board the International Space Station (ISS) has produced oxygen via water electrolysis for crew respiration. As water is consumed in the OGS recirculating water loop, make-up water is furnished by the ISS potable water bus. The make-up water passes through an Inlet Deionizing Bed (IDB) to protect the OGS from the iodine that is added as a disinfectant. In addition to the intended function to remove iodine (and iodide) from the make-up water, the IDB also removes other contaminant species. Resin and water samples collected from a returned IDB are analyzed to support installation life models as well as to better understand the role of the IDB in OGS water chemistry. The results of analysis of resin and water samples and their impact to both the installed life of the IDB and to the chemistry of the OGS recirculation loop and other OGS components will be presented.

Nomenclature

CDRA	=	Carbon Dioxide Removal Assembly
CFU/mL	=	Colony Forming Units per milliliter
CV	=	Control Valve
ACTEX	=	Activated Carbon/Ion Exchange
DMSD	=	dimethylsilanediol
$DMSO_2$	=	dimethylsulfone
ECLS	=	Environmental Control and Life Support
EDXRF	=	Energy Dispersive X-Ray Fluorescene
ESEM	=	Environmental Scanning Electron Microscope
FTIR	=	Fourier Transform Infrared (spectroscopy)
GC-MS	=	Gas Chromatography-Mass Spectroscopy

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HF = Hydrogen Fluoride
IDB = Inlet Deionizing Bed
Inlet DI Bed = Inlet Deionizing Bed
ISS = International Space Station
ITCS = Internal Thermal Control System
JSC = Johnson Space Center
LOD = Limit of Detection
MCV = Microbial Check Valve
MEA = Membrane Electrode Assembly
mg/L = milligrams per liter
MMST = monomethylsilanetriol
µg/L = micrograms per liter
MTL = Moderate Temperature Loop
ppb = parts per billion, equivalent to µg/L in dilute aqueous solutions
ppm = parts per million, equivalent to mg/L in dilute aqueous solutions
OGA = Oxygen Generation Assembly
OGS = Oxygen Generation System
ORU = Orbital Replaceable Unit
R&R = Remove and Replace
RSA = Rotary Separator Accumulator
SA = Sabatier Assembly
Si = Silicon
SiO_2 = Silica
SOV = Shut Off Valve
TIC = Total Inorganic Carbon
TOC = Total Organic Carbon
UPA = Urine Processor Assembly
V = Volts
WHC = Waste and Hygiene Compartment
WPA = Water Processor Assembly
WRS = Water Recovery System

I. Introduction

THE Oxygen Generation Assembly (OGA) located within the Oxygen Generation System (OGS) rack electrolyzes recycled feed water to form oxygen and hydrogen gases. The oxygen is vented directly to the ISS cabin atmosphere for crew respiration. The hydrogen is sent with carbon dioxide from the Carbon Dioxide Removal Assembly (CDRA) to the Sabatier Assembly (SA) where the hydrogen and carbon dioxide react to form water and methane (currently vented overboard), which improves the overall water balance on the vehicle. When the Sabatier is unavailable, hydrogen is discarded overboard through the external vent to space. In the confined and remote atmosphere of ISS, the premium energy cost of electrolysis as compared to the mass cost of delivering oxygen to station makes oxygen generation by water electrolysis an attractive option, even when hydrogen is vented overboard. The value of water electrolysis is increased with the addition of the SA and the CDRA, which utilizes the byproduct hydrogen and recovered CO_2 to regenerate water.

First used to produce oxygen on ISS in July of 2007, the OGA was initially fed Shuttle fuel cell water from 10-liter bags through a pressurized accumulator bellows tank mounted on the OGS rack. In November of 2008, the Water Recovery System racks (WRS-1 and WRS-2) were installed to produce potable water for crew consumption, for operation of the Waste & Hygiene Compartment (WHC), and for oxygen generation in the OGA. Potable water destined for the OGA passes through an Inlet Deionizing Bed (Inlet DI Bed or IDB) to remove iodine/iodide and coalesce entrained gas. The IDB is a cylinder containing 5560 mL (338 cubic inches) of mixed cation/anion exchange resin. If any gas bubbles are detected by a gas sensor downstream, the feed water is shunted to the waste water bus or a system shutdown occurs. This prevents oxygen entrained in the feed water from mixing with the generated hydrogen in the recirculation loop water, thereby preventing a potentially combustible mixture. In the OGA, water is electrolyzed to yield oxygen and hydrogen gases in the Hydrogen Dome ORU, which contains the electrolysis cell stack, sensors, valves and a Rotary Separator Accumulator (RSA). The RSA separates the two phase cathode (water and hydrogen)

side product hydrogen gas from the water. Water is recirculated by the positive displacement Pump ORU through filters, an ion exchange bed, delta-pressure sensors, and a heat exchanger that sends waste heat to an ISS Internal Thermal Control System (ITCS) Moderate Temperature Loop (MTL). The hydrogen dome provides multiple leak and fracture containment barriers in the event of a failure. Figure 1 shows a simplified OGA diagram. As water is consumed, additional Water Processor Assembly (WPA) product water is added to the recirculation loop via batch fills. As of April 10, 2018, 13,868 pounds of oxygen (and 1747 pounds of hydrogen) have been produced for crew on ISS.

The operational role of the IDB is to remove iodine and iodide from the feed water prior to entering the OGA. Iodine is added as a disinfectant to suppress microbial activity in the WPA product water, resulting in a mix of iodine and iodide in the water. Both iodine and iodide must be prevented from entering the OGS cell stack where they could poison the catalyst in the electrolytic cell stack. The resin in the IDB also retains other chemical species, thereby delaying or preventing their buildup in the OGA recirculation loop. IDB S/N 00002 was installed prior to initial OGA operation and was removed November 8, 2016. Water throughput for this ORU was approximately 5700 lbs of OGA operation water and an estimated 72 lbs of water diverted through the OGA reject line to the ISS waste bus. The amount of water through the reject line included some intentional shunt volume related to high conductivity readings in the WPA, which required extended reprocessing. The high conductivity readings were linked to problems in the Urine Processor Assembly (UPA). The primary goal of analysis of the IDB S/N 00002 resin was to measure the amount of iodine and other contaminants retained on the resin and to use that data to improve installed lifetime estimates by UTAS[1] and Boeing.

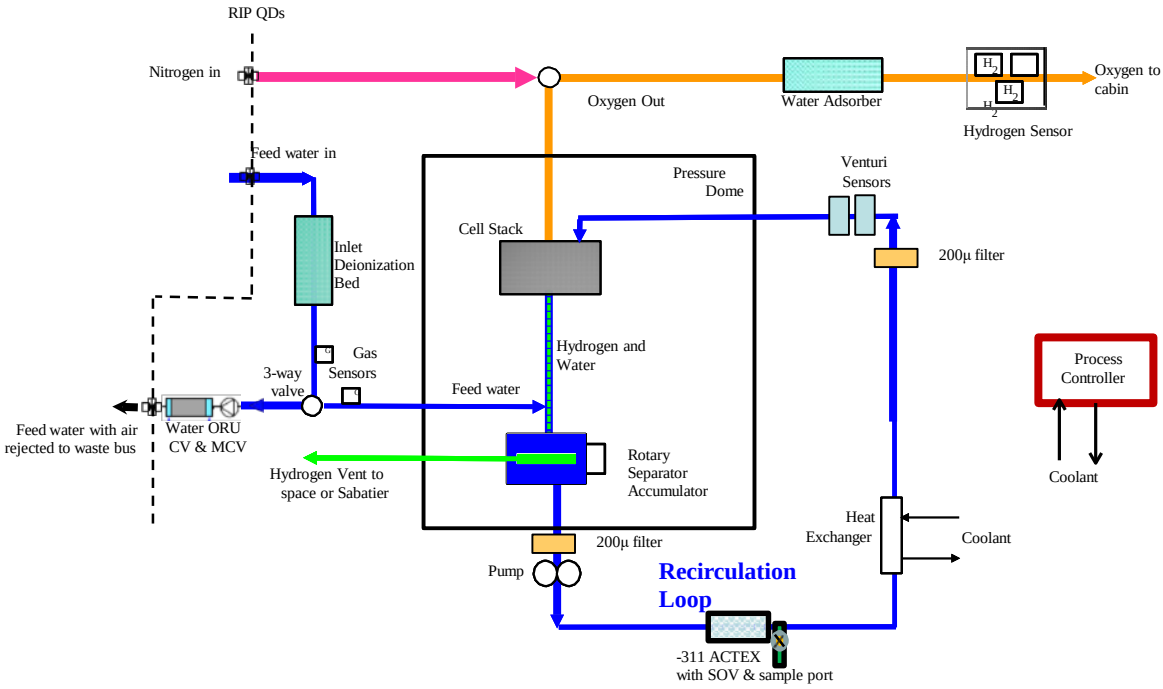

Figure 1. Simplified Oxygen Generation Assembly (OGA) diagram.

II. Methods

After removal on November 8, 2016, IDB S/N 00002 was returned to ground on Space-X 10 in March 2017 and arrived at UTAS on July 18, 2017. United Technologies and Aerospace Systems (UTAS) personnel aseptically sampled the resin on December 7, 2017, using clean, sterilized scoops and containers according to the schematic shown in Figure 2. At the top surface of the resin, 5 x 10 mL microbial samples collected and combined into a 50 mL tube. This was repeated for the first chemical sample, and then approximately one liter or resin was removed. The sequence was repeated until the entire volume was sampled, resulting in 7 pairs of 50 mL tubes along with the larger volumes of resin removed. Each 50 mL tube represents a random mixed resin fraction sample at that level or layer.

After collection, samples were kept cool through storage, shipping, receipt, and subsampling for analysis at Boeing Huntsville Central Laboratories.

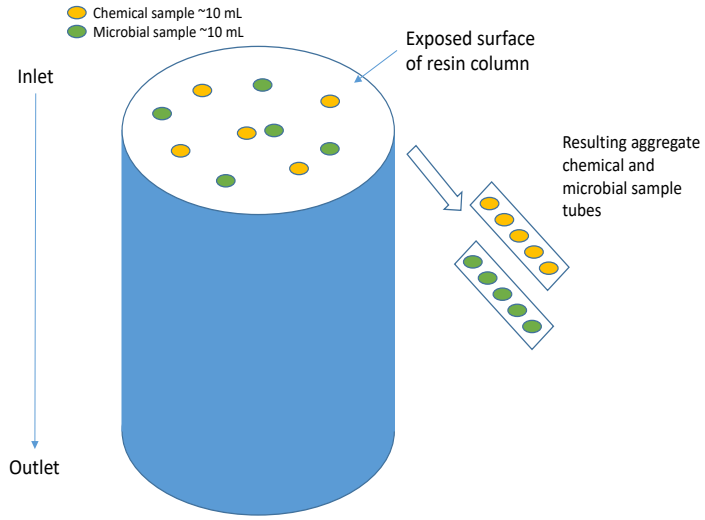

Figure 2. Resin sample collection schematic. *At the top surface, 5 x 10 mL samples microbial samples collected and combined into a 50 mL tube. This was repeated for the first chemical sample, and then approximately one liter or resin was removed. The sequence was repeated until the entire volume was sampled, resulting in 7 pairs of 50 mL tubes along with the larger volumes of resin removed.*

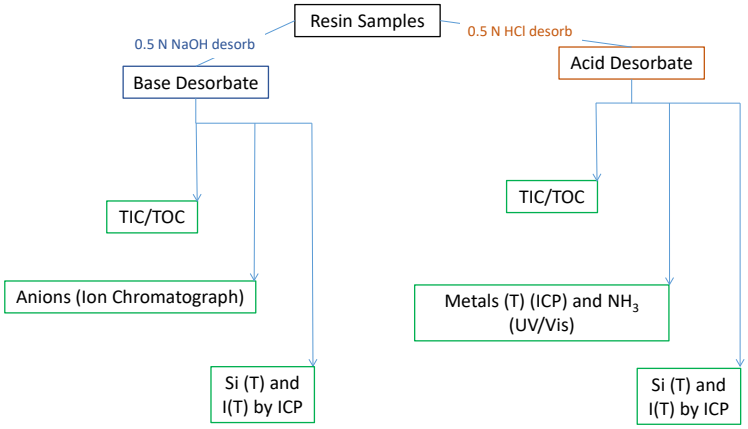

Figure 3. Resin chemical analysis schematic

Selected resin samples underwent chemical and microbial analyses to determine loadings of various constituents. The top layer (Layer 1), middle layer (Layer 4), and bottom layer (Layer 7) were analyzed. All other samples were retained in case additional analyses were required.

A schematic of the chemical analysis plan is shown in Figure 3. Separate aliquots of Layers 1-7 resin samples were desorbed in both 0.5 M NaOH (base) and 0.5 N HCl (acid). The desorbates from Layers 1, 4, and 7 were analyzed for the various parameters. Layers 2, 3, 5, and 6 were analyzed for total silicon and total iodine only. Additional resin samples were dried to determine a conversion factor from wet weight to dry weight. The concentrations in the desorbates of various constituents were then converted to a loading per dry mass of resin. Results are reported both in mg/g dry resin and in mmol/g dry resin.

Resin layers 1-7, one swab, and water drained from the IDB were processed for microbial analysis. Resin samples were weighed, and microorganisms were released from the resin into sterile phosphate buffered saline by standard vortexing and sonication techniques. The residual water sample was vortexed and sonicated in the same manner as the resin samples. Per method 9215 of Standard Methods for the Examination of Water and Wastewater, each sample was serially diluted into sterile phosphate buffer and inoculated in duplicate onto R2A agar and mEmmon's medium using membrane filtration. R2A plates were incubated for 7 days at 28 °C for bacterial enumeration. mEmmon's plates were incubated for 5 days at room temperature for fungal enumeration. Colonies were counted after the incubation period.

Unique bacterial colony morphologies from the countable R2A plates were streaked onto fresh R2A plates and grown at 28 °C for isolation. One colony from each isolation plate was streaked onto TSBA and grown at 28 °C for 1-3 days for fatty acid methyl ester (FAME) identification, and subsequently streaked onto R2A for FAME identification if necessary. Isolates showing ambiguous or low similarity FAME results were analyzed using the Biolog Microbial ID system (Biolog, Hayward, CA). Each isolate for Biolog analysis was streaked onto TSA media and incubated at 33°C for 24-48 hours.

Unique fungal morphologies were streaked onto fresh PDA plates and grown at room temperature for isolation. Isolates were identified macroscopically by morphology and microscopically by transferring to a glass slide, staining with lactophenol cotton blue to observe microscopic cellular morphologies.

III. Results and Discussion

A. Chemical Analysis Results and Discussion

Results of chemical analysis of the acid (pink) and base (blue) desorbates for Layers 1-7 are shown in Table 1 and Table 2. Values are reported in both mg/g of dry resin and mmol/g of dry resin.

Table 1. Measurement results from acid and base extracts for Layers 1 (inlet), 4 (middle), and 7 (outlet)

Measured in Acid or Base Extract	Layer 1	Layer 4	Layer 7
TIC (present as HCO3-) resin loading, mg/g dry resin	1.10E-01	1.43E-02	5.03E-02
TIC (present as HCO3-)resin loading, mmol/g dry resin	1.81E-03	2.34E-04	8.24E-04
TOC mg/g dry resin	1.18E+00	1.52E+00	1.27E+00
TOC mmol/g dry resin	9.83E-02	1.26E-01	1.06E-01
Silver, mg/g dry resin	<LOD	<LOD	<LOD
Silver, mmol/g dry resin	<LOD	<LOD	<LOD
Al, mg/g dry resin	4.66E-04	<LOD	<LOD
Al, mmol/g dry resin	1.73E-05	<LOD	<LOD
Ba, mg/g dry resin	<LOD	<LOD	<LOD
Ba, mmol/g dry resin	<LOD	<LOD	<LOD
Ca, mg/g dry resin	3.95E-04	<LOD	<LOD
Ca, mmol/g dry resin	9.85E-06	<LOD	<LOD
Cd, mg/g dry resin	<LOD	5.60E-04	6.58E-04
Cd, mmol/g dry resin	<LOD	4.99E-06	5.85E-06
Co, mg/g dry resin	1.87E-03	1.80E-04	2.28E-04
Co, mmol/g dry resin	3.17E-05	3.06E-06	3.87E-06
Cr, mg/g dry resin	8.59E-03	8.01E-05	1.15E-04
Cr, mmol/g dry resin	1.65E-04	1.54E-06	2.22E-06
Cu, mg/g dry resin	4.97E-04	<LOD	4.40E-04
Cu, mmol/g dry resin	7.83E-06	<LOD	6.93E-06
Fe, mg/g dry resin	1.41E-02	7.19E-04	1.63E-03
Fe, mmol/g dry resin	2.70E-04	1.38E-05	3.13E-05
Mg, mg/g dry resin	2.04E-03	3.22E-04	4.16E-04
Mg, mmol/g dry resin	8.38E-05	1.33E-05	1.71E-05
Mn, mg/g dry resin	2.96E-03	7.64E-05	1.29E-04
Mn, mmol/g dry resin	5.38E-05	1.39E-06	2.36E-06
Mo, mg/g dry resin	<LOD	<LOD	<LOD
Mo, mmol/g dry resin	<LOD	<LOD	<LOD
Ni, mg/g dry resin	1.29E+01	1.46E+00	2.03E+00
Ni, mmol/g dry resin	2.20E-01	2.49E-02	3.47E-02
Ni, mg/year	2.45E+03	2.35E+02	2.45E+02
Pb, mg/g dry resin	2.25E-03	7.19E-04	7.18E-04

Measured in Acid or Base Extract	Layer 1	Layer 4	Layer 7
Pb, mmol/g dry resin	1.08E-05	3.47E-06	3.46E-06
Ti, mg/g dry resin	4.50E-03	<LOD	<LOD
Ti, mmol/g dry resin	9.39E-05	<LOD	<LOD
Zn, mg/g dry resin	7.79E-02	9.30E-03	1.14E-02
Zn, mmol/g dry resin	1.19E-03	1.42E-04	1.75E-04
Na, mg/g dry resin	4.37E-02	1.90E-02	2.03E-02
Na, mmol/g dry resin	1.90E-03	8.26E-04	8.85E-04
K, mg/g dry resin	3.49E-03	2.16E-06	<LOD
K, mmol/g dry resin	2.05E-03	1.27E-06	<LOD
Ammonium, mg/g	<LOD	<LOD	<LOD
Ammonium, mmol/g	<LOD	<LOD	<LOD
TIC (present as HCO3-) resin loading, mg/g dry resin	2.47E+00	2.86E-01	2.49E-01
TIC (present as HCO3-)resin loading, mmol/g dry resin	4.04E-02	4.69E-03	4.09E-03
TOC mg/g dry resin	1.45E+00	1.52E+00	1.33E+00
TOC mmol/g dry resin	1.21E-01	1.27E-01	1.11E-01
Fluoride, mg/g dry resin	<LOD	<LOD	<LOD
Fluoride, mmol/g dry resin	<LOD	<LOD	<LOD
chloride, mg/g dry resin	<LOD	7.38E-03	7.46E-03
chloride, mmol/g dry resin	<LOD	2.08E-04	2.10E-04
nitrite, mg/g dry resin	<LOD	1.35E-03	<LOD
nitrite, mmol/g dry resin	<LOD	2.94E-05	<LOD
bromide, ppm	<LOD	<LOD	<LOD
nitrate, mg/g dry resin	<LOD	2.40E-03	3.22E-03
nitrate, mmol/g dry resin	<LOD	3.87E-05	5.20E-05
phosphate, mg/g dry resin	9.33E-01	1.03E-01	1.44E-01
phosphate, mmol/g dry resin	9.83E-03	1.09E-03	1.51E-03
sulfate, mg/g dry resin	8.14E-02	3.88E-02	3.61E-02
sulfate, mmol/g dry resin	8.48E-04	4.04E-04	3.76E-04

Table 2. Iodine and silicon measurements for Layers 1-7 in acid and base extracts.

Sample	Iodine, mg/g dry resin	Iodine, mmol/g dry resin	Si, mg/g dry resin	Si, mmol/g dry resin
Layer 1 Acid Extract	1.16E+01	9.17E-02	3.35E-01	1.19E-02
Layer 2 Acid Extract	1.19E+00	9.39E-03	1.80E+00	6.42E-02
Layer 3 Acid Extract	4.10E-01	3.23E-03	1.64E+00	5.85E-02
Layer 4 Acid Extract	1.33E-01	1.05E-03	4.46E-01	1.59E-02
Layer 5 Acid Extract	1.39E-01	1.09E-03	3.11E-01	1.11E-02
Layer 6 Acid Extract	1.36E-01	1.08E-03	7.19E-02	2.56E-03
Layer 7 Acid Extract	1.17E-01	9.22E-04	7.39E-02	2.63E-03
Layer 1 Base Extract	2.33E+00	1.84E-02	3.23E-02	1.15E-03
Layer 2 Base Extract	1.74E-01	1.37E-03	1.75E+00	6.23E-02
Layer 3 Base Extract	4.92E-02	3.88E-04	8.25E-01	2.94E-02
Layer 4 Base Extract	1.40E-02	1.10E-04	2.84E-01	1.01E-02
Layer 5 Base Extract	9.19E-03	7.24E-05	1.82E-01	6.47E-03
Layer 6 Base Extract	8.75E-03	6.90E-05	4.13E-02	1.47E-03
Layer 7 Base Extract	1.01E-02	7.94E-05	4.23E-02	1.51E-03

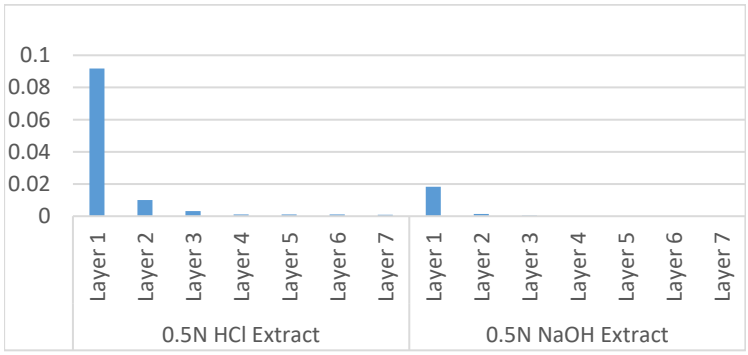

Figure 4. Total iodine measured in acid and base extracts, mmol/g dry resin.

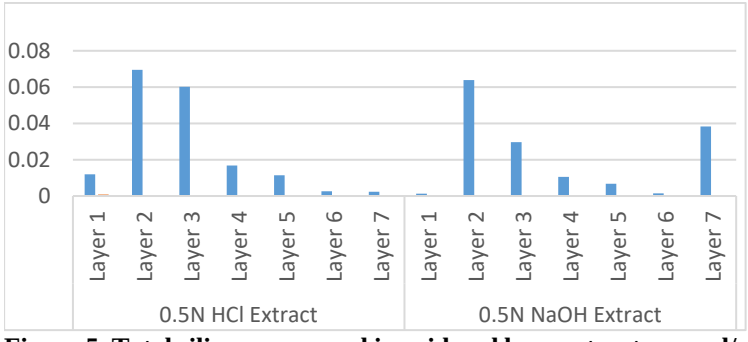

Figure 5. Total silicon measured in acid and base extracts, mmol/g dry resin.

The primary purpose of the IDB is to remove iodine/iodide. For this analysis, total iodine was measured by ICP-OES, which does not distinguish between iodine and iodide. It is likely that ionic iodide is the primary form on the resin. Iodide has a very strong affinity for anion exchange resins. Both acid and base desorbates were measured for total iodine. Results are graphed in Figure 4. It is possible that the acid released more iodine both because chloride is a stronger anion than hydroxide and because the acid may break down the resin more easily than the base. The total amount of iodine on the resin is estimated at approximately 30 g. The total amount of iodine in 6200 L with an average predicted concentration of 2.75 mg/L iodine is 17 g. The amount of iodine recovered from the resin is reasonable and indicates good recovery by the desorption method. These results show clearly that the IDB effectively removes iodine, successfully protecting the OGS.

Silicon was measured on all seven layers, and results are shown in Figure 5. Similar profiles for both acid and base extracts are expected. The primary silicon containing species are expected to be dimethylsilanediol (DMSD), monomethylsilanetriol (MMST), and silica (SiO_2), which all have relatively neutral character and are weakly enough bound to the resin to be removed by either the chloride or hydroxide. Due to the relatively strong acid and base solutions used to desorb the resin samples, DMSD and MMST cannot be directly

measured. SiO_2 can be measured and, with Total Organic Carbon (TOC), was previously used to infer relative amounts of DMSD and MMST on the OGS recirculation loop ACTEX-311. (1) However, in the case of the IDB, the amount of measured TOC greatly exceeds the predicted amount of MMST and DMSD based on the non-SiO_2 silicon measured. It is possible that the acid and base degraded the resin, as indicated by a relatively constant level of TOC across all of the samples. Further work is underway to characterize the measured TOC.

Figure 6 shows a graph of other anions measured on selected resin samples: Total Inorganic Carbon (TIC) present as bicarbonate ion, phosphate ion, and sulfate ion. Bicarbonate is present as a result of the Teflon® flex-hoses in which the product water flows. Carbon dioxide from the ISS cabin atmosphere permeates through the Teflon® and dissolves in the water where it converts to carbonic acid, which dissociates bicarbonate ion. The large size of the IDB easily captures the amount of bicarbonate present, and the conductivity sensor downstream of the IDB confirms that no measurable bicarbonate is being added with the OGS feed water. This is important because bicarbonate in the OGS recirculation loop interferes with the ability of the ACTEX-311 mixed ion exchange resin to remove and retain fluoride. Fluoride is a degradation product of the cell stack membrane material and must be removed to ensure continued operation of the OGS.[2]

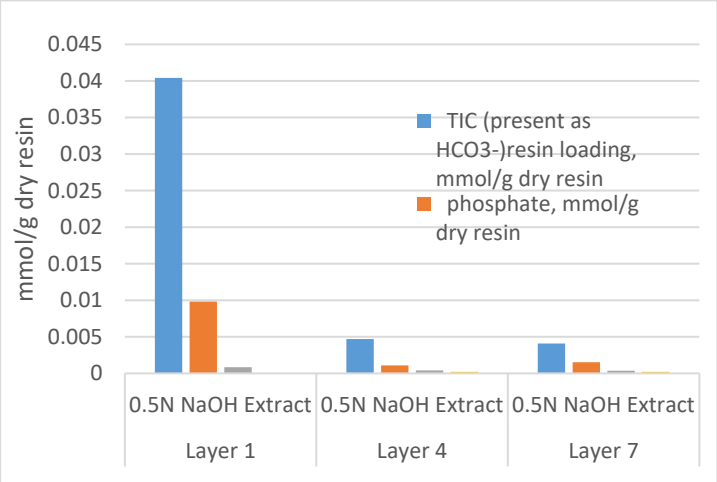

Figure 6. TIC (bicarbonate), phosphate, and sulfate measured in selected base extracts, mmol/g dry resin.

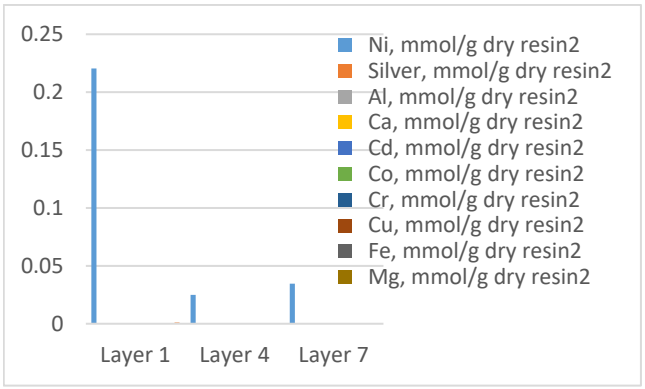

Figure 8. Nickel (Ni) and other cations, mmol/g dry resin.

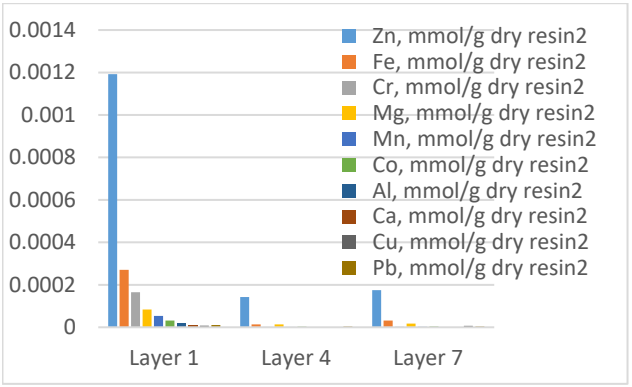

Figure 7. Cations excluding nickel, mmol/g dry resin.

Nickel was the most abundant cation (Figure 7) with higher loadings than iodine. Other cations were relatively low compared to anions. These ions represent amounts captured over the several years of IDB installation. Other cations include zinc, iron, chromium, and others as shown in Figure 8.

Previous installed life estimates were based on initial predictions of WPA product water ionic content and on predicted OGS usage, which defined IDB throughput. The estimates were updated and installed life extended as actual throughput (and OGS usage rates) became available. The amount and location of iodine captured by the resin can be used to further improve installed life estimates for the IDB. Iodine was observed near the inlet, indicating that it is better retained than other anions and polar species observed in the downstream resin samples. The observed cations, and nickel in particular, do not appear to interfere with iodine retention. The amount of iodine observed is reasonable for the amount of water flowed through the IDB. This information suggests that the expected iodine content of WPA product water may be safely used to predict installed lifetime instead of the more conservative approach based on total ionic content of the product water. Additionally, the possibility of microbial growth to the extent that it might affect flow has been shown to be unlikely with this and previous deionizing bed analyses.

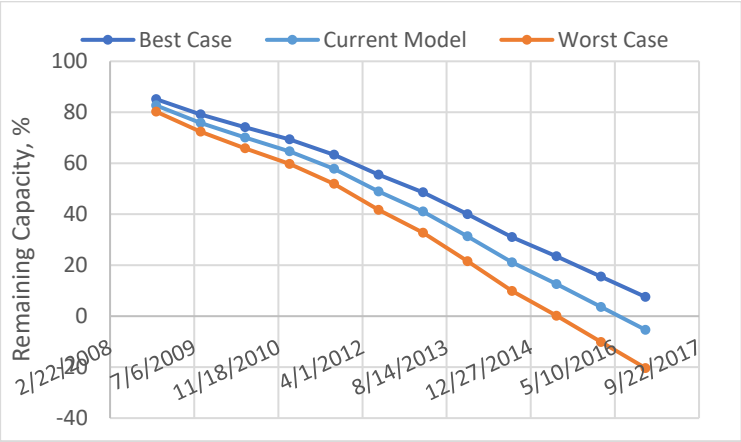

Figure 9. Previously predicted remaining capacity during IDB installed life based on total ionic content. *This prediction is based on the original predicted total ionic content of WPA product water, actual OGS operating throughput, and estimated reject line and shunt volumes.*

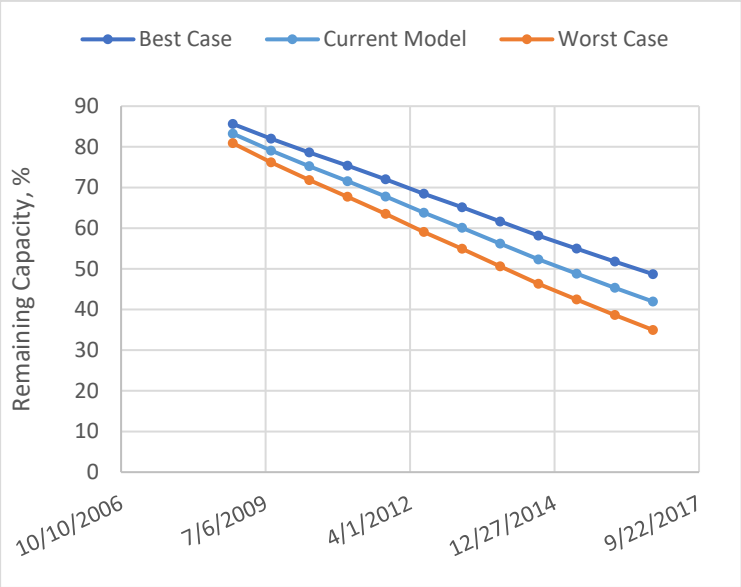

Figure 10. Predicted remaining capacity during IDB installed life based on iodine. *This prediction is based on 2.75 mg/L iodine, actual OGS operating throughput, and estimated reject line and shunt volumes.*

Figure 9 graphically shows a prediction from the original model for remaining capacity over the installed lifetime of the IDB. This model used total ion content of the water in case other anions interfered with iodine retention and to prevent those anions from entering the OGS recirculation loop. The capacity at installation is less than 100% because this model also incorporates a resin degradation rate of 6% per year with a margin of about +/- 1%. Work is underway at Johnson Space Center (JSC) to better understand degradation rate, as 6% is likely an overly conservative estimate based on conversations with resin suppliers. The “best” and “worst” cases arise from ranges in degradation rate and ion exchange resin capacity based on manufacturer information.

Figure 10 graphs predicted remaining resin capacity based on 2.75 mg/L iodine, actual OGS operating throughput, and estimated reject line and shunt volumes. Based on the measured iodine in the resin desorbates, this model more accurately reflects remaining useful capacity. However, while the initial model may be overly conservative, considering iodine alone is overly optimistic. Although the original intent of IDB installation was to protect the OGS from iodine/iodide, it also protects the system from bicarbonate, silica, DMSD, and MMST. Bicarbonate is undesirable in the recirculation loop feed water because it is preferentially retained over fluoride on the ACTEX-311 resin. It is possible that silica also plays a role in fluoride retention. The best estimation method going forward would take into account iodine, bicarbonate, and silicon. The data shown here addresses iodine only. Further analysis is needed to add bicarbonate and silicon species to the model. Currently, the iodine based model could be

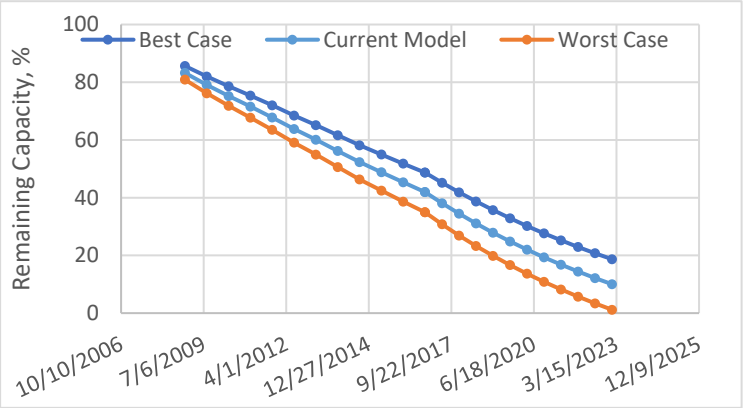

Figure 11. Predicted remaining capacity if IDB S/N 0002 been left in place past 11/8/2016. *This prediction is based on 2.75 mg/L iodine, actual and estimated OGS operating throughput based on current OGS usage rates, and actual shunt and estimated reject line and volumes.*

used under two conditions: 1) the ACTEX-311 or other deionizing bed in the recirculation loop effectively removes silica, DMSD, and MMST (and bicarbonate), and 2) the conductivity sensor downstream of the IDB continues to show that no ionic content is added to the recirculation loop. An alternative removal mechanism for silica, DMSD, and MMST would be a periodic flush of the loop water, which could be effected in future designs.

Finally, Figure **11** adds prediction of remaining capacity if the IDB were left in place past the actual R&R date of 11/8/2016 with current operating conditions, using the same model and margins as in Figure 10. Note the break in curve shape at the actual R&R date. This is due to the usage rate of S/N 00002, which was ramped up over time in a way that coincidentally offset the degradation rate. The curve in the line after actual R&R date shows the increased effect of predicted resin degradation rate as the resin ages. While this chart suggest that the currently installed IDB S/N 00003 may have a much longer life than S/N 0002 under similar water quality and annual throughput, other species such as bicarbonate should also be considered. Additionally, this calculation must be updated to include projected crew numbers and their associated oxygen needs. Monitoring of the downstream conductivity meter output and the health of the OGS recirculation loop (via semi-annual return-to-ground sample analysis) will help ensure that the cell stack is adequately protected.

B. Microbial Analysis Results and Discussion

The IDB samples showed evidence of microbial growth but not enough to affect flow or resin performance. This is in part due to the fact that the bed is exposed primarily to iodinated water that is relatively low in carbon nutrient sources. Heterotrophic bacteria in the OGA DI Inlet Bed were detected in resin layer 1 (1.36×10^4 CFU/g dry weight), resin layer 2 (1.32×10^2 CFU/g dry weight), and the water drain sample (72 CFU/mL) (Table 3, Figure 12). Bacteria were below the detection limit in resin layers 3 through 7 and the swab sample. Yeast and filamentous fungi were only present in the QD swab sample (2 CFU/swab). Identification of the bacterial isolates indicated that *Bradyrhizobium japonicum* was the most prevalent bacteria in the samples (Table 4). The fungi on the swab was identified as *Chrysosporium* species. *Bradyrhizobium* has been detected in the OGS feedwater and recirculation loop, the WPA system, and ground test OGS samples. Low match *Bradyrhizobium* organisms have been detected previously in the ECLS condensate samples. Low match *Phylobacterium* bacterium and *Chrysosporium* species have previously been detected in ground tests. Given the low prevalence of *Chrysosporium* species in the single swab sample, it must also be considered that these organisms are common sampling contaminants. All organisms are categorized as Biosafety Level 1 biohazards.

Table 3. Total microbial enumerations

Total heterotrophic bacteria: R2A 7-day membrane filtration count		
Sample ID	**CFU Count**	**Units**
Layer 1	1.36×10^4	CFU/g dry weight
Layer 2	1.32×10^2	CFU/g dry weight
Layer 3	< 3	CFU/g dry weight
Layer 4	< 3	CFU/g dry weight
Layer 5	< 3	CFU/g dry weight
Layer 6	< 3	CFU/g dry weight
Layer 7	< 3	CFU/g dry weight
Swab	< 3	CFU/swab
Water	72	CFU/mL
Total yeast and filamentous fungi: mEmmon's 5-day membrane filtration count		
Sample ID	**CFU Count**	**Units**
Layer 1	< 2	CFU/g dry weight
Layer 2	< 3	CFU/g dry weight
Swab	5	CFU/swab
Water	< 1	CFU/mL

Table 4. Bacterial, yeast, and filamentous fungi isolate identification and enumeration

Sample ID	Isolate #	Bacterial Identification (R2A)	Count (CFU/g or CFU/mL)	Method
Layer 1	1	*Bradyrhizobium japonicum*	1.17×10^4	FAME
Layer 1	2	Low match *Bradyrhizobium*	1.89×10^3	FAME
Layer 2	1	*Bradyrhizobium japonicum*	1.30×10^2	FAME
Water	1	*Bradyrhizobium japonicum*	70	FAME
Water	2	Low match *Phyllobacterium*	2	FAME
Sample ID	**Isolate #**	**Yeast and filamentous fungi identification (PDA)**	**Count (CFU/swab)**	**Method**
Swab	1	*Chrysosporium* species	5	Microscope

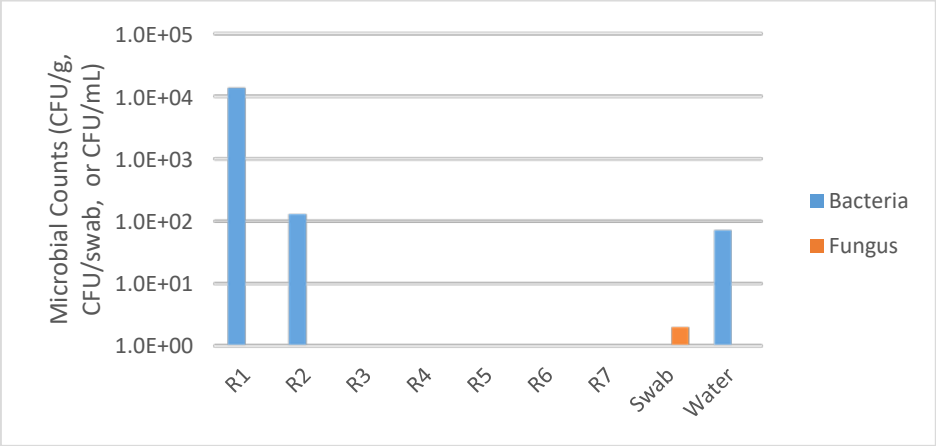

Figure 12. Total microbial counts of heterotrophic bacteria (blue) and fungi (orange) in the resin (CFU/g), swab (CFU/swab), and water (CFU/mL) samples.

IV. Conclusion

Analysis of the returned IDB expended resin samples, in conjunction with return product water sample analyses and water quality models, serve to refine current remaining capacity models and predict and manage installed lifetime of the IDB. The original prediction models for remaining capacity over the installed lifetime of the IDB were likely overly conservative. The conservative model used total ion content of the water in case other anions interfered with iodine retention and to prevent those anions from entering the OGS recirculation loop. This model also incorporated a resin degradation rate of 6% per year, and testing is currently underway to refine estimates of resin degradation rate. Instead, predictions for remaining resin capacity can be based on 2.75 mg/L average iodine concentration expected in the OGA feed water with past actual and future estimated IDB water throughputs for more accurate predictions of remaining useful capacity. This estimation method may be used under two conditions: 1) the recirculation loop ACTEX-311 deionizing bed effectively remove silica, DMSD, and MMST (and bicarbonate), and 2) the conductivity sensor downstream of the IDB must continue to indicate that no ionic content is added to the recirculation loop. This updated model suggests that that the currently installed IDB S/N 00003 might have a much longer life than S/N 00002, provided that the water quality and average annual throughputs remains similar, based solely on iodine/iodide removal. Additionally, these results indicate that the IDB can be used for extended times without adverse impact from microbial growth. However, it is also suggested that installed life predictions must be updated to include bicarbonate, silicon species, updated resin degradation rates, projected OGS usage rates, and projected reject/shunt volumes going forward. For any predicted installed life model use, monitoring of the IDB downstream conductivity meter and health of the OGS recirculation loop water via semi-annual return-to-ground sample analyses will help ensure that the cell stack is adequately protected from water contaminants.

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