

Status of ISS Water Management and Recovery

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Water management on ISS is responsible for the provision of water to the crew for drinking water, food preparation, and hygiene, to the Oxygen Generation System (OGS) for oxygen production via electrolysis, to the Waste & Hygiene Compartment (WHC) for flush water, and for experiments on ISS. This paper summarizes water management activities on the ISS US Segment, and provides a status of the performance and issues related to the operation of the Water Processor Assembly (WPA) and Urine Processor Assembly (UPA). This paper summarizes the on-orbit status as of May 2011, and describes the technical challenges encountered and lessons learned over the past year.

I. Introduction

The International Space Station (ISS) Water Recovery and Management (WRM) System insures availability of potable water for crew drinking and hygiene, oxygen generation, urinal flush water, and payloads as required. To support this function, waste water is collected in the form of crew urine and crew latent, and subsequently processed by the Water Recovery System (WRS) to potable water. This product water is provided to the potable bus for the various users, and is supplemented as required by fuel cell water transferred from the Shuttle when it is docked to ISS. The WRS is comprised of the Urine Processor Assembly (UPA) and Water Processor Assembly (WPA). The Water Recovery System is located in two ISPR racks, named WRS#1 and WRS#2. This hardware was delivered to ISS on STS-126 on November 14, 2008 and initially installed in the US Lab module. On February 18, 2010, the racks were transferred to their permanent home in the Node 3.

II. Description of the ISS Water Recovery and Management System

The ISS WRM provides the capability to receive the waste water on ISS (crew urine and latent), process the waste water to potable standards via the WRS, and distribute potable water to users on the potable bus. A conceptual schematic of the WRM is provided as Figure 1. The waste water bus receives crew latent from the Common Cabin Air Assemblies (CCAA) on ISS, which condenses water vapor and other condensable contaminants and delivers the condensate to the bus via a water separator. In addition, waste water is also received from the Carbon Dioxide Reduction System, which was installed in the last year in the Node 3 OGS Rack. This hardware uses Sabatier technology to produce water from carbon dioxide (from the Carbon Dioxide Removal Assembly

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(CDRA)) and hydrogen (from the electrolysis process in the Oxygen Generation System). Waste water is typically delivered to the WPA Waste Tank, though the Condensate Tank located in the US Laboratory Module is available in the event the WPA Waste Tank is disconnected from the waste bus. In this scenario, the crew must manually connect the Condensate Tank to the waste water bus. Once the WPA Waste Tank is online again, the crew will disconnect the Condensate Tank from the waste water bus. Condensate collected in this scenario must subsequently be offloaded into a Contingency Water Container (CWC). The CWC can then be emptied into the WPA waste tank via a pump, or transferred to the Russian Segment for processing by the Russian Condensate Processor (referred to as the SRV-K).

Crew urine is collected in the Waste & Hygiene Compartment (WHC), which includes the Russian Urinal (referred to as the ACY). Urine is chemically treated to maintain chemical and microbial control, and flush water is added. The pretreated urine is then delivered to the Urine Processor Assembly (UPA) for subsequent processing. The UPA produces urine distillate, which is pumped directly to the WPA waste water tank, where it is combined with the crew latent and Sabatier product water and subsequently processed by the WPA. A detailed description of the UPA and WPA treatment process is provided in Section III.

After the waste water is processed by the WRS, it is delivered to the potable bus. The potable bus is maintained at a pressure of approximately 230 to 280 kPa (19 to 26.5 psig) so that water is available on demand from the various users. Users of potable water on the bus include the Oxygen Generation System (OGS), the WHC (for flush water), the Potable Water Dispenser (PWD), and Payloads.

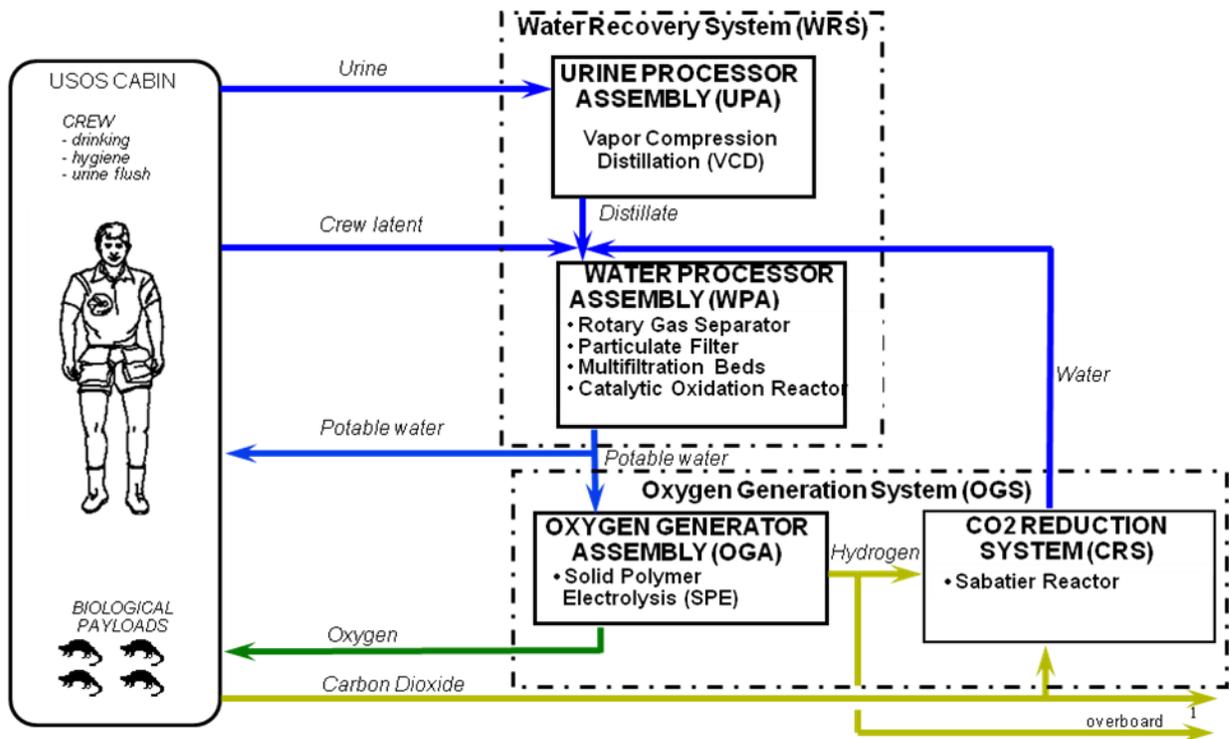


Figure 1. Water Recovery and Management Architecture for ISS US Segment

III. Description of the ISS Water Recovery System

The layout of the two WRS racks is shown in Figure 2, along with the OGS. The WPA is packaged entirely in WRS Rack #1 and partially in WRS Rack #2, linked by process water lines running between the two racks. The remaining portion of WRS Rack #2 houses the UPA.

The following section provides a description of the WRS, current operational status, and describes issues and lessons learned during the past year. For the prior years' status, see references 1-3.

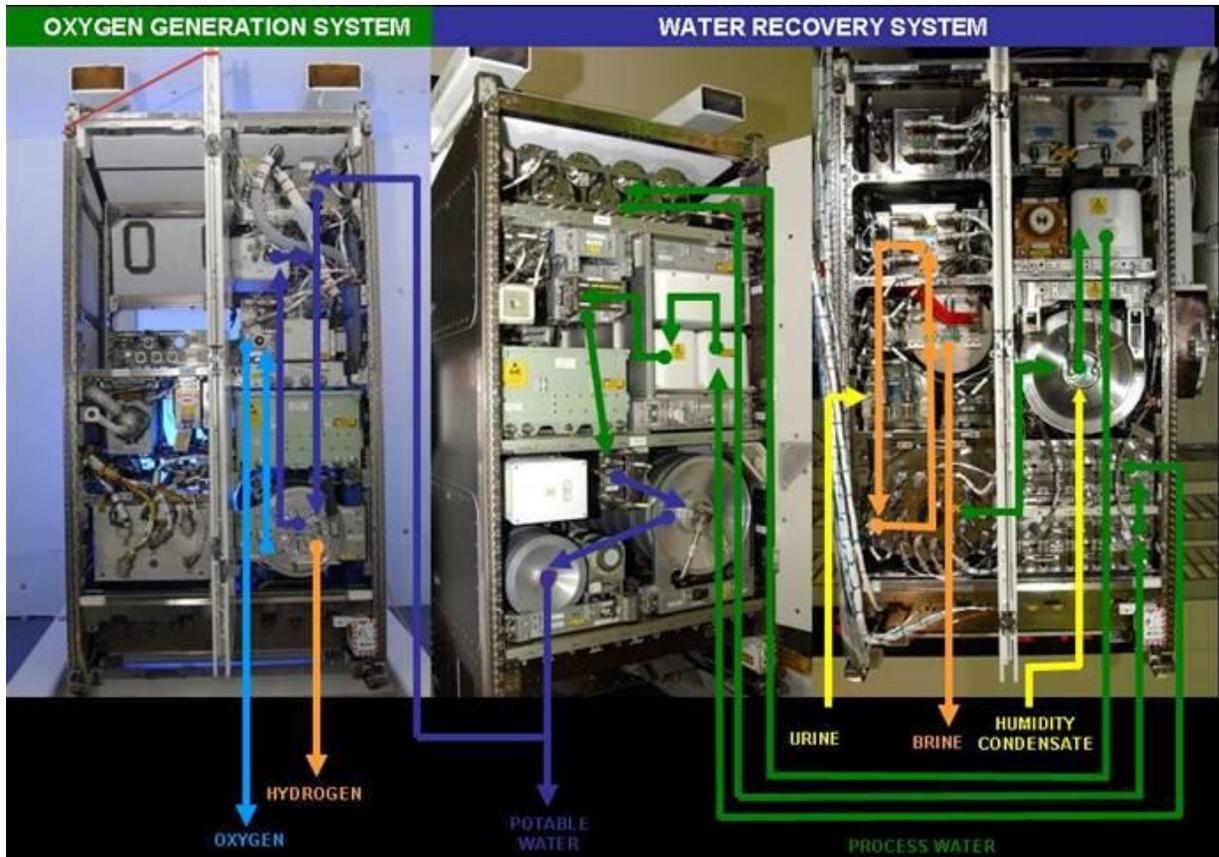


Figure 2. International Space Station Regenerative ECLSS Racks

A. Water Processor Assembly Overview

A simplified schematic of the WPA is provided in Figure 3. Wastewater delivered to the WPA includes condensate from the Temperature and Humidity Control System and distillate from the UPA. This wastewater is temporarily stored in the Waste Water Tank Orbital Replacement Unit (ORU). The Waste Water Tank includes a bellows that maintains a pressure of approximately 5.2 – 15.5 kPa (0.75 to 2.25 psig) over the tank cycle, which serves to push water and gas into the Mostly Liquid Separator (MLS). Gas is removed from the wastewater by the MLS (part of the Pump/Separator ORU), and passes through the Separator Filter ORU where odor-causing contaminants are removed from entrained air before returning the air to the cabin. Next, the water is pumped through the Particulate Filter ORU followed by two Multifiltration (MF) Beds where inorganic and non-volatile organic contaminants are removed. Once breakthrough of the first bed is detected, the second bed is relocated into the first bed position, and a new second bed is installed. The Sensor ORU located between the two MF beds helps to determine when the first bed is saturated based on conductivity. Following the MF Beds, the process water stream enters the Catalytic Reactor ORU, where low molecular weight organics not removed by the adsorption process are oxidized in the presence of oxygen, elevated temperature, and a catalyst. A regenerative heat exchanger recovers heat from the catalytic reactor effluent water to make this process more efficient. The Gas Separator ORU removes excess oxygen and gaseous oxidation by-products from the process water and returns it to the cabin. The Reactor Health Sensor ORU monitors the conductivity of the reactor effluent as an indication of whether the organic load coming into the reactor is within the reactor’s oxidative capacity. Finally, the Ion Exchange Bed ORU removes dissolved products of oxidation and adds iodine for residual microbial control. The water is subsequently stored in the product water tank prior to delivery to the ISS potable water bus. The Water Delivery ORU contains a pump and small accumulator tank to deliver potable water on demand to users. The WPA is controlled by a firmware controller.

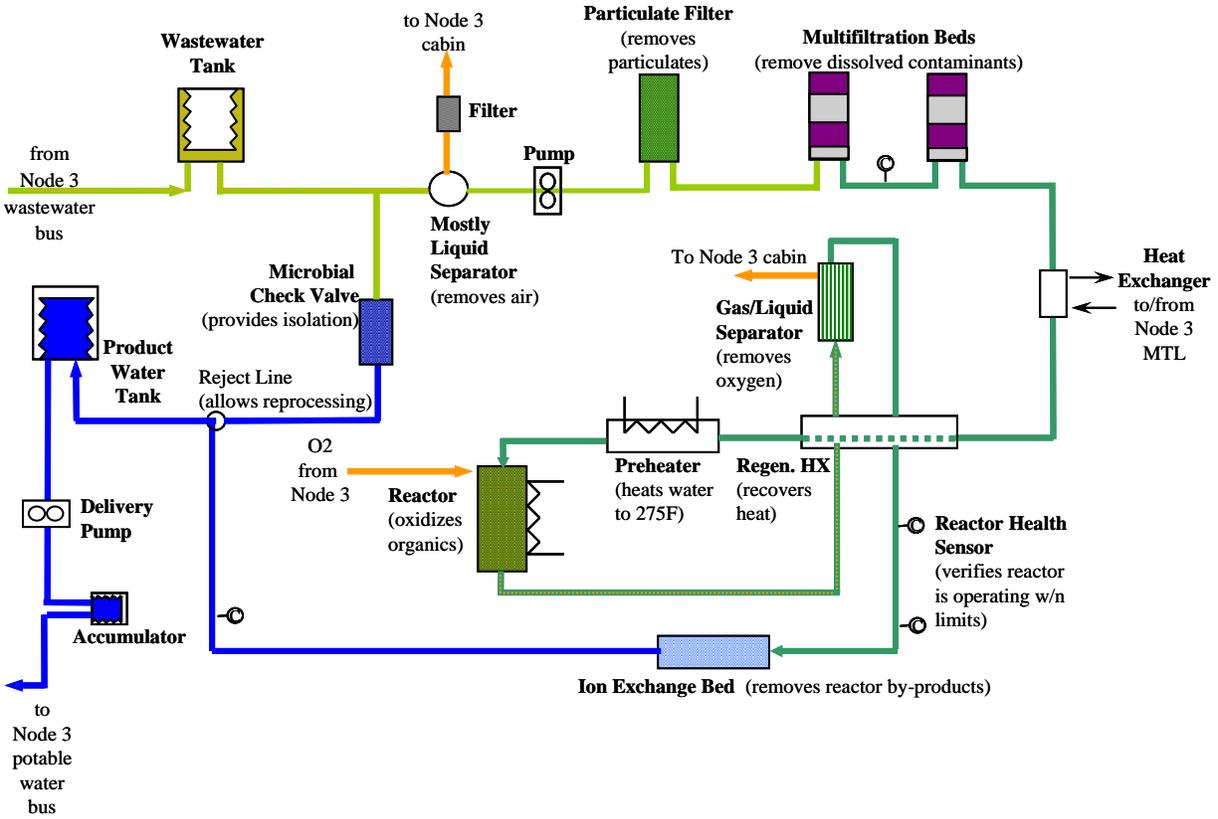


Figure 3. WPA Simplified Schematic

B. Urine Processor Assembly Overview

A simplified schematic of the UPA is shown in Figure 4. Pretreated urine is delivered to the UPA either from the USOS Waste and Hygiene Compartment (outfitted with the Russian urinal) or it can be supplied via manual transfer from the Russian urine container (called an EDV). In either case, the composition of the pretreated urine is the same, including urine, flush water, and a pretreatment formula containing chromium trioxide and sulfuric acid to control microbial growth and the reaction of urea to ammonia. The urine is temporarily stored in the Wastewater Storage Tank Assembly (WSTA). When a sufficient quantity of feed has been collected in the WSTA, a process cycle is automatically initiated. The Fluids Control and Pump Assembly (FCPA) is a four-tube peristaltic pump that moves urine from the WSTA into the Distillation Assembly (DA), recycles the concentrated waste from the DA into the Recycle Filter Tank Assembly (RFTA) and back to the DA, and pumps product distillate from the DA to the wastewater interface with the WPA. The DA is the heart of the UPA, and consists of a rotating centrifuge where the waste urine stream is evaporated at low pressure. The vapor is compressed and subsequently condensed on the opposite side of the evaporator surface to conserve latent energy. A rotary lobe compressor provides the driving force for the evaporation and compression of water vapor. Waste brine resulting from the distillation process is stored in the RFTA, which has a capacity of approximately 41 L. When the brine is concentrated to the required limit, the RFTA is replaced with an empty RFTA, which allows the process to repeat. The full RFTA is returned to the ground on the Shuttle for refurbishment so it can be returned to ISS for another cycle. The Pressure Control and Pump Assembly (PCPA) is another four-tube peristaltic pump which provides for the removal of non-condensable gases and water vapor from the DA. Liquid cooling of the pump housing promotes condensation, thus reducing the required volumetric capacity of the peristaltic pump. Gases and condensed water are pumped to the Separator Plumbing Assembly (SPA), which recovers and returns water from the purge gases to the product water stream. A Firmware Controller Assembly (FCA) provides the command control, excitation, monitoring, and data downlink for UPA sensors and effectors.

The UPA was designed to process a nominal load of 9 kg/day (19.8 lbs/day) of wastewater consisting of urine and flush water. This is the equivalent of a 6-crew load on ISS. Product water from the UPA must meet specification quality requirements for conductivity, pH, ammonia, particles, and total organic carbon. The UPA was designed to recover 85% of the water content from the pretreated urine, though issues with urine quality encountered in the last year have required the recovery to be dropped to 70%.

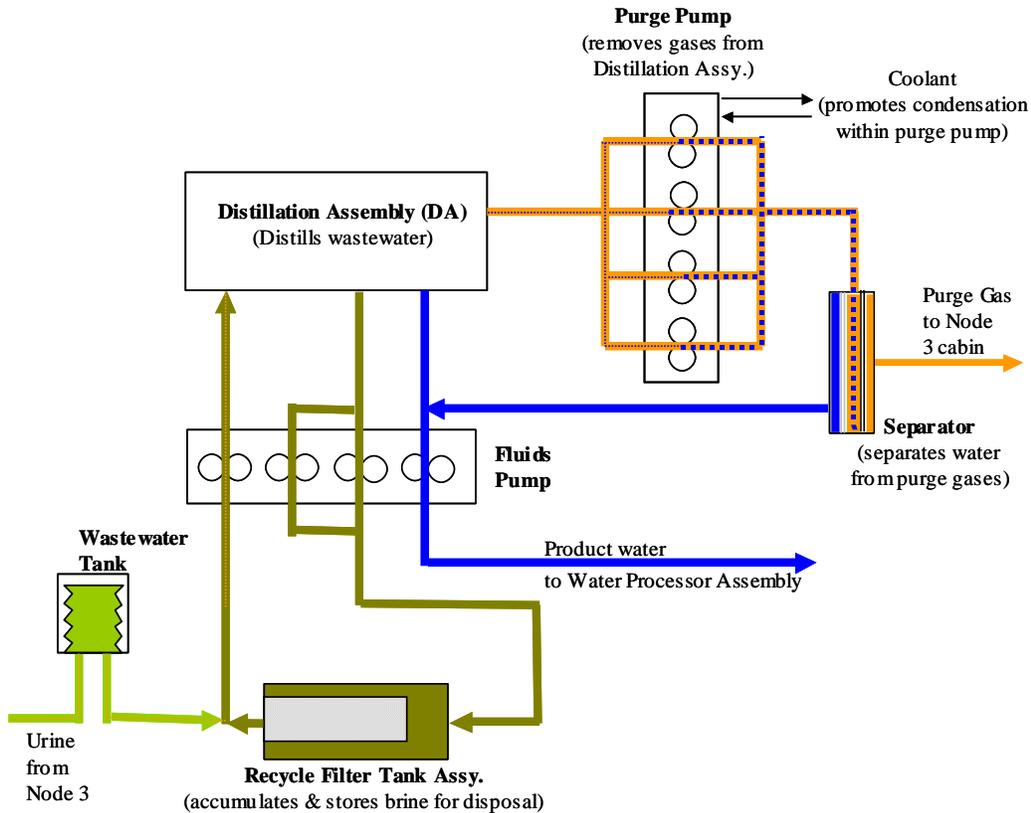


Figure 4. Urine Processor Assembly Schematic

The UPA is packaged into 7 ORUs, which take up slightly more than half of the WRS Rack #2. The RFTA is the only expendable ORU, sized for a 30-day replacement schedule when processing the daily urine load from 6 crewmembers.

IV. Water Recovery and Management Status

In the last year, 3010 L of potable water have been supplied to the US Segment potable bus for crew use and for the OGS. A more detailed assessment of the US Segment mass balance and operational issues can be found in Reference 4. Since the US Segment typically produces more water than is used by the crew, periodically excess potable water must be transferred to a CWC-I. A CWC-I is a CWC compatible with the iodine used as a biocide in the US potable water. Prior to installation of the WRS in November 2008, a Water Delivery System (WDS) was installed on ISS to provide a means to supply pressurized water from a CWC-I to the OGS. This system was disassembled and only used once (when WPA was offline in early 2010 due to a failure to the Catalytic Reactor) after WRS was installed, since WDS occupied valuable space in the crew cabin. Therefore, the only potable water that could be supplied to the potable bus was water produced by the WPA. However, hardware was delivered to ISS in the past year that now provides a way to transfer potable water from a CWC-I back to the potable bus without deploying the WDS. This hardware includes a tee that allows water from a CWC-I (located in the ISS cabin) to be transferred directly into the WPA Storage Tank, where it can subsequently be fed back to the potable bus by the WPA Delivery Pump. This new capability has simplified mass balance operations, since a CWC-I transfer only requires the crew to connect the CWC-I to the tee and open a manual valve. However, two significant issues have occurred in the past year that impact WRM operations.

The first issue is related to the presence of free gas on the potable bus. Free gas is a significant issue in micro-gravity, since it cannot be removed from the water without a gas separator. Since the WPA is designed to deliver water that contains no free gas, no such capability was developed for the potable bus. Previously, free gas has caused issues on the potable bus when the WDS was in use, since it would periodically transfer a limited quantity of free gas when emptying a CWC-I. This primarily affected the Potable Water Dispenser (PWD), as free gas would bind up the microbial filter in the PWD and require crew time to vent the gas or replace the filter. In addition, free gas can accumulate in the WHC flush water tank. When this free gas is fed to the WHC urinal, instrumentation detects that the pretreatment quality is unacceptable and informs the crew with an LED signal in the WHC rack. As a result, crew time is required to clear the free gas. In March 2011, a significant quantity of free gas was inadvertently transferred from a CWC-I to the WPA Storage Tank. The reason for this is pending investigation, though available data from ISS indicates the CWC-I allowed free gas to leak in from the cabin during the transfer. As a result of this event, several liters of free gas were transferred to the WHC flush tank and urinal operations were significantly impacted. Eventually the flush tank was replaced before nominal operations could be restored. Though most of the free gas was fed to the WHC, the PWD was also impacted when the free gas occluded the microbial filter. However, the crew was able to recover PWD operation by performing multiple dispenses. Engineering personnel are currently developing operational and/or hardware modifications to insure that free gas cannot be transferred to the potable bus during a CWC-I transfer.

The second issue that has impacted WRM operations in the last year has been leaking CWC-Is. The CWC-I is a plastic bladder used for storing water, with a Quick Disconnect (QD) for mating to desired interfaces. The interface between the QD and the plastic bladder was redesigned in 2009 due to leaks observed in the original design. However, 5 of the redesigned CWC-Is have also leaked in the last year, requiring a new assessment of this hardware. Most of these leaks are expected to be a result of crew handling and storage that has exceeded stress levels at the interface between the QD and the bladder. Several of the leaking CWC-Is are being returned on Shuttle flight ULF7 to confirm the failure. Engineering personnel are developing improved operational controls to minimize stresses at the QD interface, while also considering design modifications that may be required to provide a more robust container for water on ISS.

V. Urine Processor Assembly Current Status

The UPA was initially activated on November 20, 2008. Since May 17 2010, the UPA has processed 1650 L (3630 lb) of pretreated urine, producing 1120 L (2470 lb) of distillate and cycling through 12 RFTAs during that time. As of June 21, 2011, the total UPA production on ISS is at 2860 L (6300 lb) of distillate. A graphical summary of UPA production rate and upmass required for operations is provided in Figure 5. The UPA experienced no significant anomalies on ISS in the last year.

As reported previously¹, DA S/N 02 failed on October 24, 2009 due to accumulation of solids in the Distillation Assembly (see Figure 6). The root cause of the anomaly was due to the precipitation of calcium sulfate in the urine brine at the target recovery of 85%. Calcium is present in the urine primarily due to bone loss from the crew, whereas sulfate is present primarily due to the use of sulfuric acid in the urine pretreatment. Calcium levels on ISS are elevated compared to ground urine due to the absence of gravity. During ground testing, the UPA was proven to have no issues with recovering 85% of the water from pretreated urine. However, at 85% recovery on ISS, the higher concentration of calcium resulted in calcium sulfate exceeding its solubility limit. The initial response to this failure was to reduce the recovery to 70%. This level provides a 90% upper confidence limit on the calcium concentration as 283 mg/L, resulting in a low risk of precipitation occurring in the DA.

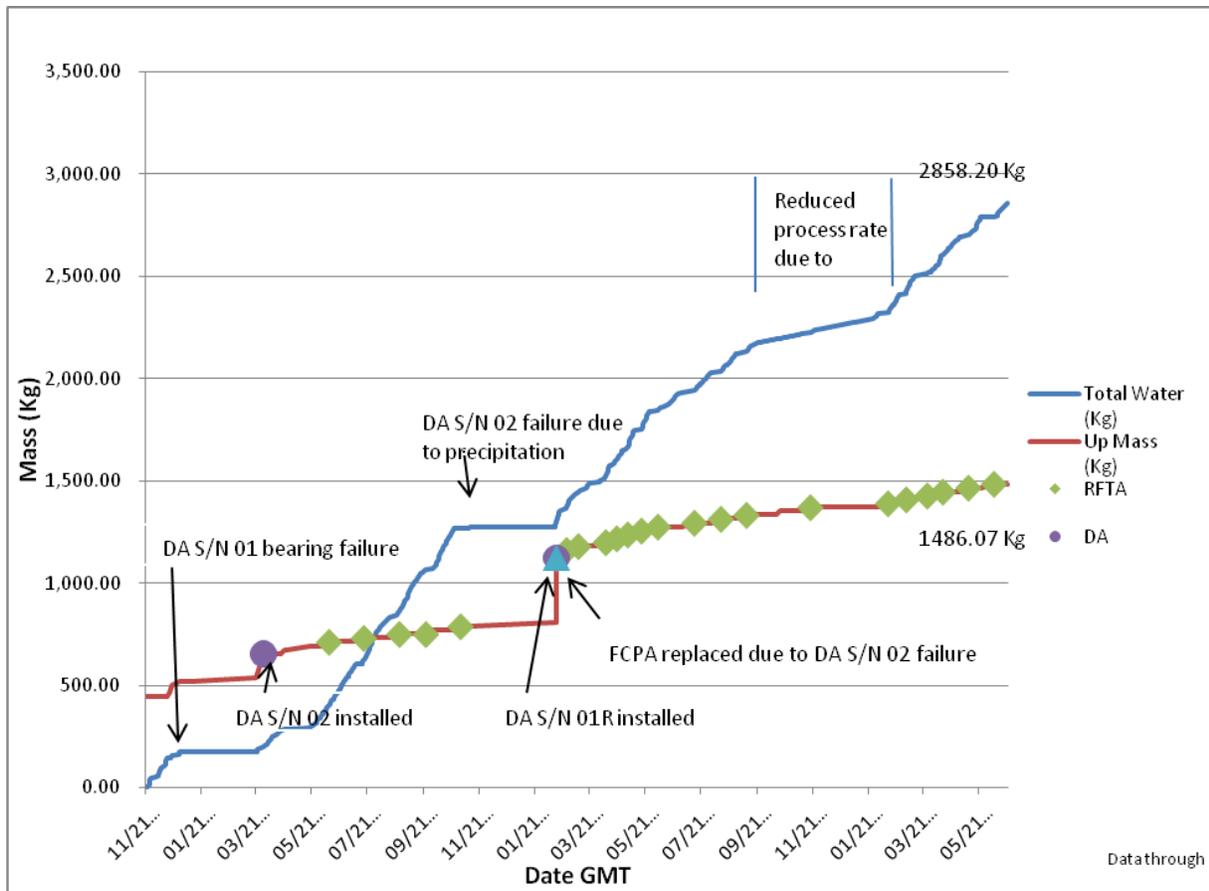


Figure 5. UPA Production and Upmass on ISS

In parallel with this modification to on-orbit operations, NASA personnel have investigated options for returning UPA to 85% recovery. A significant research effort was performed at JSC to evaluate various technology options, including ion exchange resin, chelating agents, and threshold inhibitors. Chelating agents and threshold inhibitors did not work effectively due to the low pH of the pretreated urine. Ion exchange was effective, however, and is currently in development for the flight application. Though this hardware will require significant resupply in this application, there is an obvious overall benefit due to the additional water reclaimed by returning UPA to 85% recovery. The primary option is to remove calcium from the pretreated urine as it is transferred between the WHC rack and the UPA Waste Tank. This approach has technical risk due to the limited pressure drop available in this location, but other locations were even less viable. In parallel with this approach, engineering personnel are also investigating modifications to the pretreatment formula that would eliminate or reduce the sulfate concentration, thus preventing calcium sulfate precipitation. This approach also has significant risk, as the pretreatment formula is critical for maintaining microbial and chemical control in the pretreated urine. Therefore, modifications to this formula that address calcium sulfate precipitation may create more risk in other areas. Finally, technology development is also underway on a sensor that could monitor the calcium concentration in the brine. If proven reliable, a calcium sensor would allow the UPA to concentrate the urine based on the actual calcium concentration, instead of requiring a conservative % recovery that accounts for statistical variation in the calcium concentration.

Since October 2009 (after the failure of DA S/N 02), the UPA has only processed urine collected in the US Segment WHC. This decision was made based on the analysis of pretreated urine collected in the Russian Segment in early 2010. This pretreated urine had an elevated pH of 2.46, and also contained non-viable biomass. These observations indicated there may be operational differences with the urinal in the Russian segment that could impact urine quality and subsequently UPA performance. Engineering personnel determined that additional analysis of urine collected in the Russian segment must be performed to provide confidence that the previous result was an aberration. A method was thus developed to sample pretreated urine from the EDVs used to collect urine in the Russian segment. 5 samples have been collected to date, with additional samples planned for return on Shuttle flight

ULF7. These results will be analyzed in late 2011 before deciding if the Russian urine can again be processed by the UPA.



Figure 6. Precipitation in the Distillation Assembly Evaporator

A significant operational change anticipated for the UPA in 2011 is the integration of the Advanced RFTA (ARFTA). This hardware will replace the current RFTA with a bellows assembly that can be drained and emptied on ISS. The ARFTA implements a bellows that operates at a subambient pressure to support filling the tank from the UPA Waste Tank. This is similar to the approach used to fill the RFTA, except that the RFTA provides more pressure drop for fluid flow in this configuration because it is launched and delivered to ISS at vacuum pressure. Engineering personnel at MSFC have performed ground tests to provide confidence that the ARFTA can be filled from the UPA Waste Tank with the available pressure drop. Once the ARFTA tank is full, the UPA will complete a nominal concentration cycle, with the exception that the UPA can only process 126 L (278 lb) of pretreated urine due to the reduced operating volume of the ARFTA tank. When the concentration cycle is complete, the ARFTA tank will be removed from the rack. A compressor will be used to pressurize the gas side of the bellows and thus empty the brine into either a Temporary Urine/Brine Storage System (TUBSS), the Progress Rodnik tank, a Russian EDV, or ATV tanks. Figure 7 provides a simplified schematic of the drain configuration. TUBSS will only be used to temporarily store the brine until Rodnik or ATV tanks are available. Two ARFTA tanks are scheduled for delivery on Shuttle flight ULF7 and will be operated immediately thereafter to verify functionality.

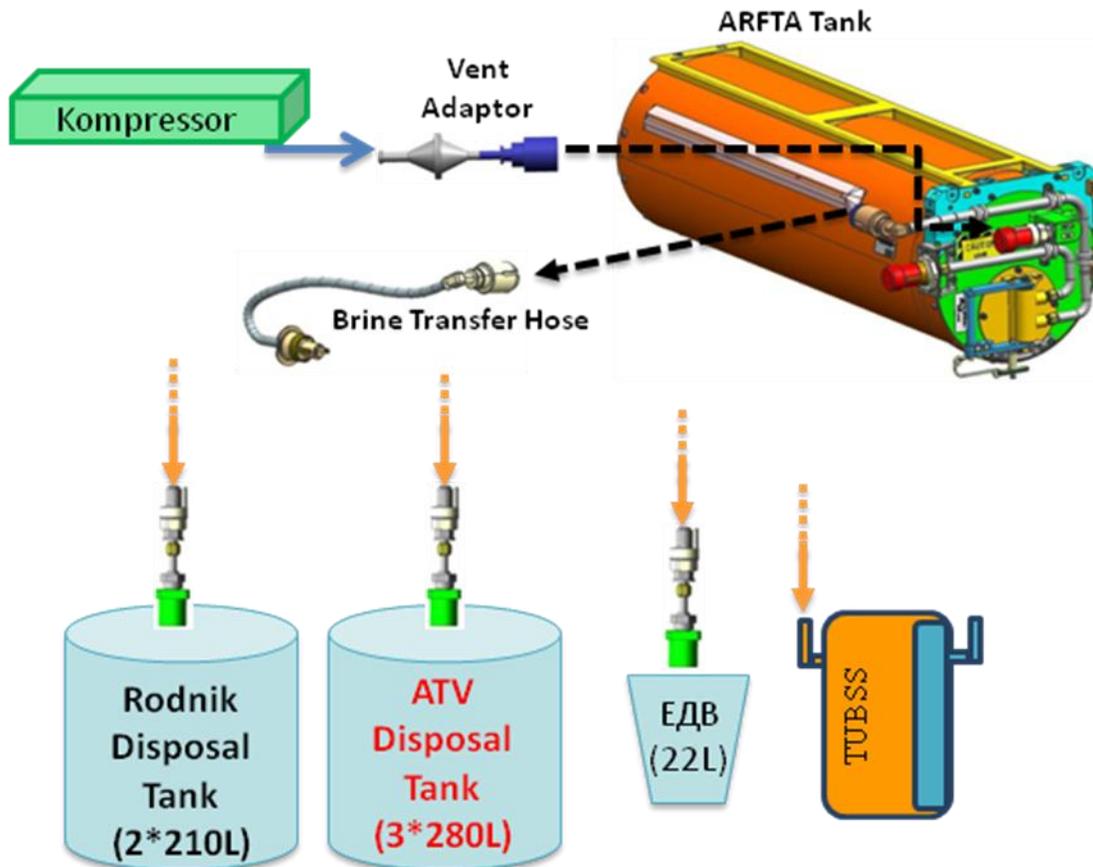


Figure 7. Drain Configuration for the ARFTA Tank

VI. Water Processor Assembly Current Status

The WPA was initially activated on November 22, 2008. As of June 20, 2011, the WPA has processed approximately 7140 kg (15740 lb) of waste water, including 3010 kg (6640 lb) in the last year.

Two anomalies have occurred to the WPA in the past year on ISS. First, an increasing trend in the WPA Total Organic Carbon (TOC) concentration was detected by the ISS TOC Analyzer (TOCA) in June 2010. Initially both Multifiltration Beds were replaced (on July 29 2010, after 4611 kg (10166 lb) of throughput during their use on ISS) based on the possibility that organic breakthrough was impacting performance of the Catalytic Reactor. However, after two weeks, there was no change in the product water TOC. The increasing trend continued until late October, at which point it rapidly decreased to nominal levels which have been maintained since (see Figure 8). Analysis of the product water during this time ultimately identified the source of the TOC in the product water as dimethylsilanediol (DMSD). DMSD is a common by-product of the degradation of polydimethylsiloxanes (PDMS), which are common compounds present in various products, including caulks, adhesives, lubricants, and hygiene products. Various PDMS compounds are prevalent on ISS, and analysis of current and previous condensate samples from ISS also indicates that DMSD has been present in the WPA waste water since WPA operations began on ISS. In addition, 37 mg/L of DMSD was detected in an analysis of a sample of the MF Bed effluent taken before the beds were replaced on July 29, indicating these MF Beds were ineffective at removal of DMSD. However, subsequent analysis of an MF Bed effluent sample taken on October 28 2010 detected no DMSD above the detection limit of 0.4 mg/L. This result indicates the MF Beds were removing the DMSD, though there is no credible theory as to why the MF Beds would begin removing a contaminant after it had already passed through the ion exchange and adsorbent media. As a polar, low molecular organic, DMSD is not expected to be well removed by adsorption or ion exchange, a statement that is corroborated by the fact that the contaminant also quickly passed through the another cartridge containing ion exchange resin and adsorbent media. This hardware (identified as the ACTEX cartridge) is located upstream of the ISS Potable Water Dispenser for removing iodine from the WPA product water before crew consumption, and was replaced during the TOC trend as part of routine maintenance. The results show

a momentary decrease in DMSD followed by a return to the same trend, thus displaying the fact that DMSD is not effectively removed by adsorbent media. NASA personnel will continue to monitor this parameter in the effort to explain the unique response by the WPA. A detailed discussion of this investigation and the analytical results can also be found in Reference 5.

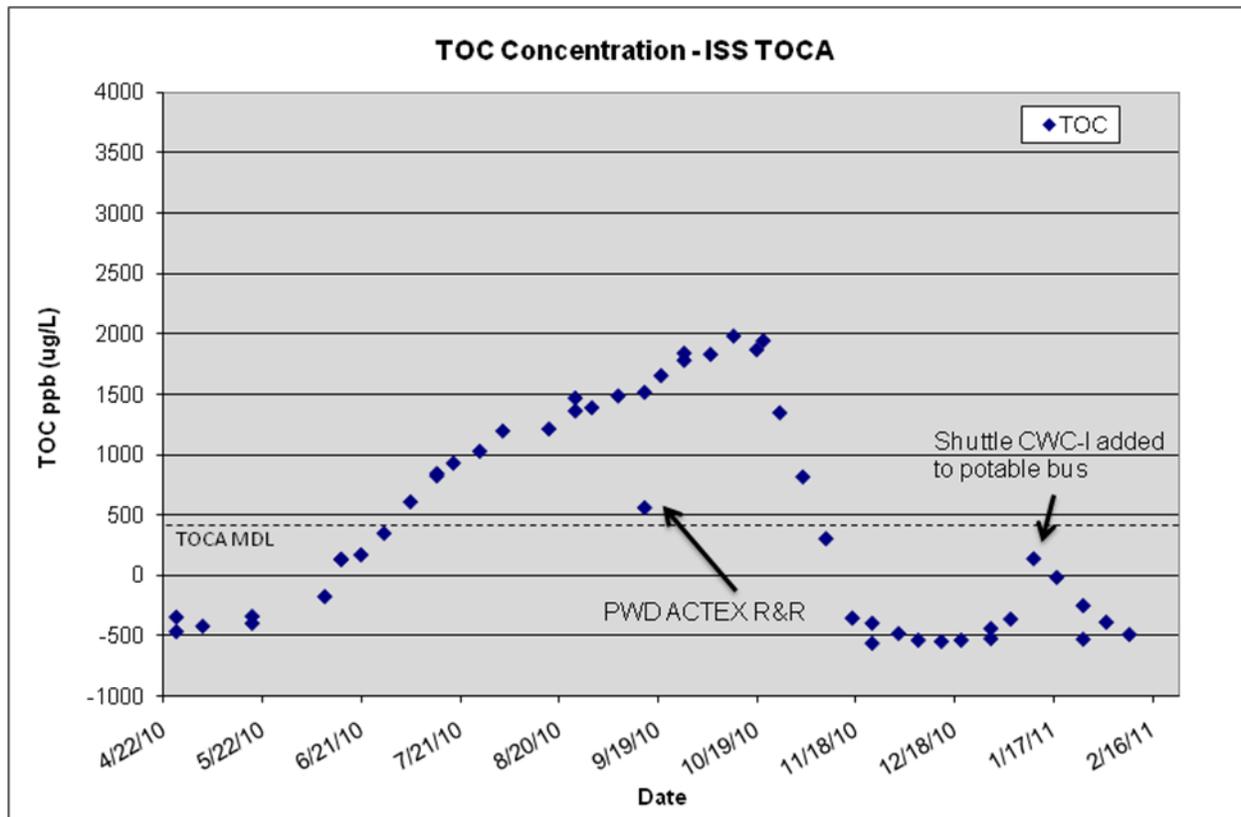


Figure 8. WPA TOC Trend

The second WPA anomaly was increased pressure drop between the waste tank and the Mostly Liquid Separator (MLS) in January 2011. This anomaly was consistent with the previous anomaly¹ that occurred in late 2009 and was resolved in early 2010 with the removal and replacement (R&R) of the Pump/Separator ORU. The root cause for the previous anomaly was determined to be the accumulation of biomass in the inlet solenoid valve to the MLS. After replacement of the Pump/Sep ORU, a waste water filter was installed between the Waste Tank ORU and the Pump/Separator ORU to protect the clearances in the MLS solenoid valve. During the investigation in early 2010, engineering personnel noted that the Waste Tank outlet solenoid valve (in the same flow path) also had the same clearances as the MLS inlet solenoid valve, though a pressure drop analysis indicated acceptable performance from the Waste Tank solenoid valve (whereas the MLS inlet solenoid valve showed significant pressure drop). However, engineering personnel recognized the risk that the Waste Tank solenoid valve could later experience the same fate. Therefore, a review of the hazards analysis for the Waste Tank solenoid valve determined that this component was not critical to WPA operations or safety, and the decision was made to remove it if required. Based on the pressure drop analysis in February and March 2010, it was determined that the Waste Tank solenoid valve and the filter (installed to protect the MLS inlet solenoid valve) both required maintenance. On March 22 2011, crew removed the Waste Tank solenoid valve and capped the line (allowing flow through the passageway), and replaced the waste water filter with a new filter. Subsequent process cycles showed significant improvement in the pressure drop, resulting in nominal WPA performance.

Both the solenoid valve and the filter were returned to the ground for investigation on ULF6. Investigation of the filter identified a biomass had coated the filter surface area, and had extruded and/or grown through the filter. Figure 9 provides a photograph of the inlet to the filter. These results confirm that the biomass is continuing to exist in the WPA Waste Tank, and is likely passing through the filter and continuing to contaminate downstream

components. Engineering personnel are currently evaluating these results to determine if any additional hardware or operational changes are required to maintain WPA operations.



Figure 9. Waste Water Filter Inlet

As noted previously, the Multifiltration Beds were replaced in July 2010 as part of the TOC trend investigation. Effluent conductivity data had indicated initial breakthrough of the first Multifiltration Bed, thus the throughput of 4611 kg is a valid estimate for the life of future units. The Separator Filter (used to remove odors from gas vented by the MLS) was replaced as part of schedule maintenance for this item. This ORU will be returned to Hamilton Sundstrand on Shuttle ULF6 to assess remaining capacity. As of April 2011, there are no indications that the Particulate Filter is loading after approximately 2.5 years of operation on ISS. Scheduled replacement (after three years of operation) of the Ion Exchange Bed ORU will occur in the next year.

VII. Conclusion

In the past year, the WRS has continued to provide the ISS crew with potable water for drinking, electrolysis via the Oxygen Generation System, flush water for the Waste & Hygiene Compartment, and hygiene water. The UPA has operated nominally in the past year, though at a reduced water recovery of 70% to prevent precipitation of calcium sulfate in the brine. The goal is to reclaim 85% recovery in the next year based on ongoing technology development.

The WPA has experienced and recovered from two operational issues. As noted, crew maintenance recovered the WPA from the pressure drop anomaly observed in early 2011. Engineering and science personnel continue to investigate the presence of DMSD in the WPA product water from June to November 2010, primarily to prevent a recurrence that could eventually render the WPA product unacceptable for use on ISS.

Acknowledgments

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