Lessons Learned for the International Space Station Potable Water Dispenser

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The International Space Station (ISS) Potable Water Dispenser (PWD) currently provides potable water for United States On-orbit Segment crew consumption in food and drink packages. The first PWD unit commenced on-orbit operation in early 2009 and is certified for 10 years of operation. A second PWD unit began development 3 years after the certification of the first PWD unit to extend support of the ISS beyond 2018. A number of design changes were incorporated into the second PWD unit based upon the on-orbit experience with the first PWD unit over those 3 years. Operational changes were developed in response to on-orbit issues, including the certification of a shock kit to address unacceptable microbial growth prior to PWD activation. A major redesign of the primary crew interface was developed to increase the ease of use and robustness of the system. This redesign was incorporated into the base design of the second PWD unit and also retrofitted into the first PWD unit on-orbit. Other observations over the years of sustaining the PWD have generated knowledge that can help direct the development of future potable water dispensers, such as updates to key design assumptions regarding crew and payloads usage of the PWD system. This paper will detail the lessons learned from the PWD systems to inform development of future potable water dispensing hardware for other vehicles.

Nomenclature

ACTEX = Activated Carbon/Ion Exchange
BAA = Beverage Adapter Assembly
°C = degrees Celsius
CFU = colony forming unit
COTS = commercial off-the-shelf
CWC = Contingency Water Container
EXPRESS = Expedite the Processing of Experiments to the Space Station
°F = degrees Fahrenheit
I_2 = elemental iodine
I^- = iodide
IP = International Partner
ISS = International Space Station
JSC = Johnson Space Center
lbm = pounds (mass)
LED = light-emitting diode
MCD = Microbial Capture Device
ORU = Orbital Replacement Unit
PiP = Package-in-Place
ppm = parts per million
PTFE = Polytetrafluoroethylene
PWB = Potable Water Bus
PWD = Potable Water Dispenser
TOC = Total Organic Carbon

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UV = ultraviolet
USOS = United States On-orbit Segment

I. Potable Water Dispenser Overview

THE Potable Water Dispenser (PWD) is the primary method for International Space Station (ISS) United States On-orbit Segment (USOS) crew to receive potable water for consumption in food and drink packages. The PWD is capable of dispensing hot (150°F-200°F [66°C-93°C]) or ambient (65°F-123°F [18°C-51°C]) temperature water in 25 mL increments from 25 mL up to 250 mL. To reduce system complexity, the PWD is not capable of chilling water; however, crew members can fill drink packages with ambient temperature water and place them in a separate unit (a role currently fulfilled by the ISS Microgravity Experiment Research Locker Incubator [i.e., MERLIN]) that functions as the crew's refrigerator. Crew members interface a food or drink package to the PWD dispensing needle, select the desired volume of water to be dispensed, and push the hot or ambient dispense pushbuttons located on the front panel to fill the package. The PWD receives iodinated water from the Potable Water Bus (PWB) and relies on the bus pressure to dispense water since the PWD does not contain a pump. The PWD also contains a replaceable filter consumable that removes the iodine biocide from the water and filters the water for particulates. When a pushbutton is depressed, the PWD will open the appropriate solenoid valves located throughout the system to allow water to flow from the PWB, through the PWD, which removes the iodine biocide, and into the food or drink package.

Figure 1. First PWD flight unit.

The PWD contains four operational modes: Rehydration, Flush Water, Flush Iodine, and Auxiliary. The operational mode most often used by the crew is the Rehydration mode. This mode provides potable water for crew consumption as well as providing water for other uses; e.g., dispensing potable water for payloads usage, rehydrating hygiene towels, and allowing for water quality samples to be drawn. The Flush Water and Flush Iodine contingency modes exist to help recover the PWD from high levels of bacterial growth in the system. When activated, these modes dispense 10 times the volume selected and are intended to assist first with flushing a high concentration iodine biocide through the PWD to shock the system and then flushing water through the system to remove the biocide and return to a configuration suitable for crew consumption. Finally, the Auxiliary mode allows Contingency Water Container (CWC) bags to be quickly filled via the PWD. The Auxiliary mode bypasses the PWD's filter so these CWCs are filled with the same water provided by the PWB.

Two PWD flight units currently exist. The first unit was developed, built, and certified between 2007 and 2008 and was launched on STS-126 in November 2008 (Figure 1).[1] This unit commenced on-orbit operations in early 2009 and continues operations to this day. The PWD is designed for 10 years of operation; however, the first PWD unit is currently designated to run to failure. A second PWD unit was built to support operations of the ISS beyond the original 2018 timeframe. This unit was built between 2011 and 2014 and includes design upgrades based on lessons learned from the first PWD unit. The second PWD unit is currently designated to launch on need for when the first PWD unit suffers an unrecoverable failure. During storage on the ground, the second PWD unit undergoes periodic maintenance to keep microbial growth in check and ensure hardware readiness for when it must launch to the ISS to replace the first PWD unit.

II. Design Improvements for the Second Potable Water Dispenser Unit

After the development of the first PWD unit, the ISS Program identified a need for potable water dispenser support beyond the initial 2008-2018 timeframe and directed the build and certification of a second PWD unit. Although most of the development work had been completed by 2008, initial operations of the first PWD unit revealed a few design improvements that should be included in the design of the second PWD unit. These design improvements are: replacing corrugated tubing with smooth wall tubing, adding a data port to the PWD front panel, reducing the Filter Orbital Replacement Unit (ORU) weight, and adding a blinking capability to the light-emitting diode (LED) that indicates the Filter ORU should be replaced. Additionally, the Rehydration Station portion of the first PWD unit had suffered several failures by the middle of development of the second PWD unit. In response, the ISS Program directed a design change of this section of the PWD for the second PWD unit as well as a retrofit kit to be launched separately and installed into the first PWD unit.

A. From Corrugated Tubing to Smooth Wall Tubing

The original design for the PWD contained sections of stainless steel corrugated tubing in both the ambient and hot legs. The original corrugated tubing allowed tighter bend radius of several flexible plumbing sections. After the microbial contamination issue experienced with the first PWD unit upon activation on-orbit, these sections of corrugated tubing were identified as potential locations that may assist in the formation of a biofilm because they have fluid pockets not readily flushed with water passing through the PWD. In response, these sections were updated to a smooth wall Teflon^{TM}-lined alternate in the second PWD unit. This is expected to minimize the places favorable for development of microbial proliferation in both of these legs.

B. Adding a Data Port

When the first PWD unit, operating on-orbit, experiences a failure, the fault analysis and recovery is hampered by the lack of data available from the system. Although the PWD programming does output a basic level of data, it was not anticipated that these data would be needed on-orbit; therefore, no external connector from the internal electronics board harness was provided. The data are only output real time, not recorded, and were intended to assist with the build and certification of the unit. It is possible to obtain these data by connecting the internal harness to a laptop; however, this requires the PWD chassis to be fully extended from the locker with one of the side service panels removed to allow the cable to pass through. Then, the PWD would need to be operated in this state. A data port was added to the front panel of the second PWD unit (Figure 2) to simplify this procedure. The cable harness inside the second PWD unit is connected to the data port to allow a laptop connection and download system status and pressures while the PWD is in its nominal operating configuration.

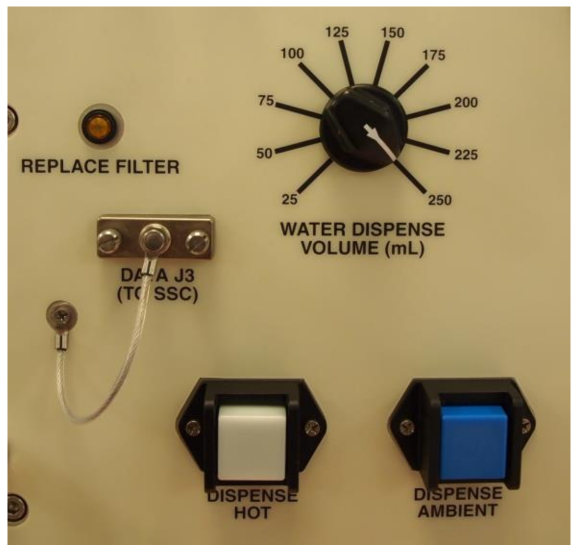


Figure 2. Second PWD unit data port.

C. Reducing Filter Orbital Replacement Unit Weight

The Filter ORU contains a deiodination filter to remove the iodine biocide from the PWB water as well as a microbial filter to filter particulates and prevent possible backflow from downstream sections back into the PWB. These consumable Filter ORUs are built and launched fairly frequently – approximately twice per year – to support the use of the PWD. The stainless steel Filter ORU cover material was changed to an aluminum alloy in an effort to reduce the weight and realize savings to the ISS Program. Design updates for the aluminum configuration include adding Koropon® between the aluminum and steel interfaces and adjusting bend radii for material properties. This reduced the total weight of the Filter ORU by approximately 30% – almost 10 lbs of weight savings per year.

D. Updating Replace Filter Light-Emitting Diode Capability

The PWD front panel contains an indicator LED (see Figure 2 'REPLACE FILTER' LED) that illuminates at a pre-determinated throughput to notify the crew that the Filter ORU is nearing its maximum certified capacity. The original design of this LED illuminates when the PWD programming has counted that approximately 90% of the Filter ORU capacity has been reached. The LED would remain solidly lit until the PWD reached the maximum throughput of the Filter ORU (programmed into the code) and then would cease to dispense. For the second PWD unit, the LED capability was updated to remain solidly illuminated upon approximately 90% Filter ORU capacity and then begin to blink once the maximum throughput had been reached. This would provide an additional indication to the crew that the PWD is not malfunctioning but has ceased to allow dispenses due to the throughput limitation.

E. Changing Rehydration Station Design

The primary crew interface on the PWD is an area on the front panel called the Rehydration Station. This area contains the dispensing needle for the crew to interface the food and drink packages for rehydration. The original design for this section included a moveable interface called the Beverage Adapter Assembly (BAA) (Figure 3). The crew member would pull out the BAA, insert the septum/tip of the food or drink package into the BAA, which would hold the package in place, then push the BAA back into place, which would pierce the food or drink package's septum onto the PWD dispensing needle. The BAA assisted in this action by lining up the septum with the needle and ensuring the food or drink package was seated an appropriate distance onto the needle; too close and the package adapter would cover the needle hole and prevent water from entering the package, too far and the water would spray outside the package. The Rehydration Station also included a Package-in-Place (PiP) switch that detected when the BAA was fully inserted into the PWD and onto the needle. If the BAA was pulled away from the PWD and needle prematurely, the PiP switch would detect this and stop the dispense early to prevent dispensing water into the open cabin.

Figure 3. Rehydration Station with Beverage Adapter Assembly.

This concept proved to be more problematic in practice than in theory.[2] The PiP switch function was a beneficial control without crew action but, in practice, it was more susceptible to damage and false signals that the food or drink package was not in position. Additionally, when water was flowing into a food or drink package, the force would push the BAA slightly away from the PWD – sometimes enough to trip the PiP switch and stop the dispense. The crew member generally had no idea how much fluid had already dispensed into the package and would have to guess at the remaining dispense volume. This would also lead to many more cycles than expected on the volume select switch and dispense pushbuttons because dispenses would end prematurely and a second was needed to finish the fill. The BAA design also unintentionally had many small crevices and holes, which would trap water that leaked, thereby leading to bacterial growth. These small areas were very difficult to clean. Additionally, the BAA design required periodic maintenance by reapplying lubrication to the mechanism's slide that was removed by inadvertent water leakage. As a result, the ISS Program directed the development of a new, simplified Rehydration Station to replace the existing Rehydration Station with BAA. This updated design would be incorporated into the in-development second PWD unit as well as retrofitted into the on-orbit first PWD unit.

Figure 4. Simplified Rehydration Station.

A few design changes were implemented to simplify the dispense operations of the PWD. The first was the decision that it was acceptable to rely on crew action for ensuring the bag was in place rather than the PiP switch. This allowed the BAA to be removed from the design. A Needle Guard Assembly was added to the Rehydration Station (top portion of Figure 4). The Needle Guard Assembly protects the crew from the functional sharp tip of the needle and potential excessive touch temperatures of the needle following a hot dispense, protects the needle from crew-induced loads, and aligns the food or drink package with the needle and controls the bag installation depth (mimicking the features of the BAA in this regard). The PiP switch changed from an automatically activated switch to a manually activated toggle located on the Rehydration Station (lower portion of Figure 4). This meant that dispenses would not be stopped prematurely but required the crew member to be more diligent about holding the package onto the needle during the entirety of the dispense. The toggle can still be activated during a dispense to immediately shut it off, should the crew member find that necessary. As a safety feature, the toggle is required to be activated after each dispense before another dispense can be performed. These changes to the PiP switch required no change to the PWD programming. Finally, the geometry of the Rehydration Station was simplified to minimize the small radius and crevices. This simplified geometry is much easier to clean when inadvertent leaks occur from the food and drink package/needle interface.

The new simplified Rehydration Station was flown as a retrofit kit for the first PWD unit on-orbit and installed in 2014. Feedback received since the installation has been positive. Crew members prefer the simplified design for dispenses, and the individual parts – now reduced to just the Needle Guard Assembly – are easier to clean. The Needle Guard Assembly dimensions allow the food or drink package to be mostly held in place due to friction, requiring only a small effort from the crew member. The elimination of premature dispense terminations has greatly reduced the number of cycles on several PWD components which will, in turn, increase their life expectancy. Overall, the update to the Rehydration Station has removed the primary crew complaint of the PWD system.

III. Operational Changes Developed in Response to On-orbit Issues

As the first PWD unit continued operations aboard the ISS, a greater understanding was gained of how the unit typically functions and where gaps in the knowledge base existed. Operational changes were made based on issues that occurred while the unit operated on-orbit. Primarily, the biggest issues pertained to bacterial growth within the fluid lines. Although the water from the PWB contains biocide, it is intended to be only strong enough to maintain bacterial levels and not disinfect the lines. Any bacteria that exist within the PWD or Filter ORU when installed on-orbit may not be cleared by the minimal biocide in the system. The PWD Filter ORU also removes the biocide to make the water meet potable water standards for consumption; therefore, sections of the system exist where no biocide is present and bacteria may grow if the fluid lines become contaminated.

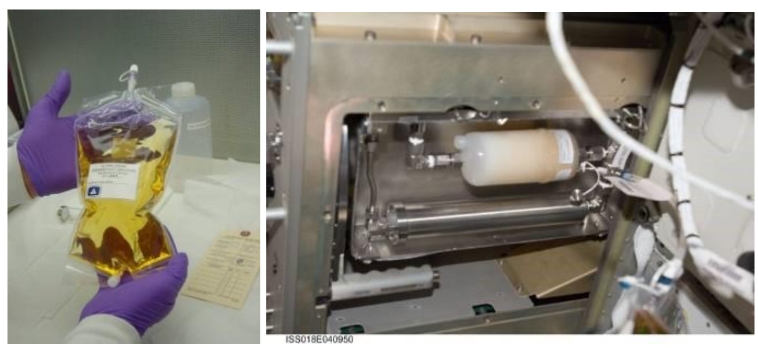


Figure 5. PWD shock kit bag (left) and shock kit in use (right).

The first PWD unit experienced a microbial upset upon installation aboard the ISS in early 2009.[3] Although the fluid lines were disinfected prior to delivery for flight, the first samples taken after activation showed a bacterial count of 85 colony forming units (CFU)/mL in the ambient fluid lines, which is above the NASA-defined on-orbit acceptability limit of 50 CFU/mL. Action was required. This action was not foreseen since the ground disinfection of the unit resulted in no detectable bacteria in both the ambient and hot legs of the system. To address this microbial contamination issue, a shock kit quickly was quickly developed consisting of 40 ppm I_2 and lauched on the next Space Shuttle flight to disinfect the system. The shock kit was administered to the particulate filter within the Filter ORU, eventually rendering the Filter ORU unsuitable for nominal use since the particulate filter absorbs a significant amount of iodine to steadily leech into the system (i.e., downstream of the deiodination filter) later (Figure 5). This solution was successful, but at the expense of a Filter ORU.

A redesign of the PWD system for easier administration of a shock kit in the second PWD unit was not an option due to limited project resources. However, a separate workaround has been developed with the expectation of this issue occurring in the second PWD unit. At the same time the second PWD unit will be prepared for launch, a shock kit will be built to be launched alongside the PWD for use immediately post-activation on-orbit. The second PWD unit will be installed once the first PWD unit fails. The partially consumed Filter ORU that is installed in the first PWD unit at the time of failure will be temporarily installed into the second PWD unit for this shock disinfection. The new Filter ORU that launched in the second PWD unit will be temporarily stowed elsewhere. Once the PWD shock is complete, the partially consumed Filter ORU will be removed and trashed, and the new Filter ORU that was launched inside the second PWD unit will be reinstalled to begin normal operations. Conducting the procedure in this manner will minimize the loss of Filter ORU capability and quickly resolve any microbial contamination issues that may have occurred in the second PWD unit during the stagnation period between final ground processing and activation on-orbit. Minimizing the downtime between the failure of the first PWD unit and operation of the second PWD unit will be important but may be at least 6 months if the second PWD unit is not launched until the first PWD unit fails (i.e., “launch on need”).

A NASA Flight Rule was also developed to better manage future microbial growth in the PWD on-orbit. This rule directs the use of the PWD and requirements for recovering from periods of stagnation. Flushes, samples, and on-orbit analyses are required depending on the length of time in stagnation. This rule was developed in conjunction with the PWD project team and Johnson Space Center (JSC) Microbiology Laboratory and has successfully kept the first PWD unit within nominal operating parameters. More information on this Flight Rule can be found in a previous ICES paper.[3]

Future potable water dispensers should include methods to easily disinfect the systems in the case of unplanned microbial contamination. Plans should be made to perform this disinfection after a long period of stagnation, regardless of the results from the final ground processing since microbial growth can be difficult to fully suppress with the biocides acceptable for space use. Potable water dispensers should minimize the unswept fluid volumes of their fluid lines to assist with these disinfections and avoid sections that can foster microbial growth. The existing PWD system contains a few dead legs, which are suspected sources of microbial contamination that is virtually impossible to completely remove with the available biocidal methods. Bacteria can reside in these areas and lead to false negatives during ground processing analyses, then grow when the system is stagnant for weeks or months. Planning as if a system shock will be required after a long period of stagnation is prudent, and facilitating this process by designing easy access in the system can minimize the cost of this disinfection.

IV. Experiences with the International Space Station Potable Water Dispenser

NASA has gained insight into the development and operations of potable water systems by operating the first PWD unit aboard the ISS for the past 9 years as well as sustaining the second PWD unit on the ground for the past 3 years. The PWD generally works well with minor issues; no major reworks or design changes are suggested. Various other observations regarding the PWD and generic potable water systems are detailed in this section.

A. Sustaining Potable Water Dispensers On Ground

The second PWD unit has periodically required moderate sustaining effort while in storage on the ground. This ongoing activity is necessary to keep bacterial growth in the system in check. In addition to consuming resources to perform these tasks, the life of the unit’s components is shortened each time the PWD is operated and the likelihood of a mishap occurring during handling of the unit increases. Preferably, the unit would require no sustaining while in storage and only necessitate preparations for launch.

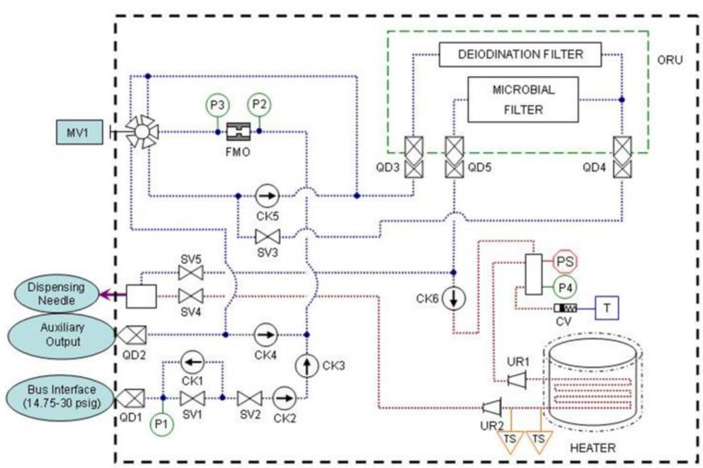


Figure 6. PWD simplified flow diagram.

The driver for periodic disinfections of the second PWD unit on the ground is the fact that the system is stored in wetted configuration. After assembly, the second PWD unit was filled with water to perform functional and certification testing. The fluid lines within the PWD are fairly complex, with many turns and dead legs (Figure 6). This complexity prohibits the ability to easily fully dry the PWD even with the use of a dry nitrogen purge. A partially wetted system that is dark, damp, and warm is a more conducive environment to bacterial growth than a fully wetted system and would be more difficult to recover. It is possible for bacterial growth to become so extensive that the system must be disassembled in order to be recovered, thus nullifying the certification testing performed on the hardware up to that point. To avoid this, the second PWD unit remains fully wetted at all times and a biannual disinfection of the entire system performed to periodically reduce the bacterial levels. A potable water system that is designed with simpler fluid lines can be disinfected and sustained more easily.

On a related matter, the PWD is required to be launched fully wetted due to the complexity of its fluid lines. One solution proposed for long-duration deep space missions is to reduce the sustaining of the potable water dispenser by fully drying the system (or launching dry) when not in use for periods of several months. If the system is sufficiently simple, it may be possible to fully dry in order to reduce maintenance. However, the system should then be designed to facilitate being fully wetted in a microgravity environment. The process to fully wet the ISS PWD is extensive and requires the 200-lb unit to be rotated in multiple orientations while simultaneously performing dispenses in a precise order to ensure that all air bubbles are removed, taking advantage of gravity to assist with the removal. Even so, the PWD project has experienced difficulty during certification testing when air bubbles have been trapped over critical sensors, which impacted PWD operations. The first PWD unit on-orbit experienced a situation where the Filter ORU was fluid locked and the PWD could not dispense because a bubble became trapped within the particulate filter in the Filter ORU. Fully wetting the ISS PWD system also requires the several solenoid valves to be manually activated in a certain order to force fluid through all fluid legs including relief lines. Special ground support equipment that interfaces directly with the electronics board is required to manually activate these solenoid valves. This connection is inherently risky because there is always the possibility that the electronics board may be accidentally bumped, or a tool dropped onto the board, or electrostatic discharge onto the components, or other mishap that causes damage to the electronics. If system wetting is to be performed in a microgravity environment, the potable water system fluid lines should be designed to accommodate this.

B. Designing for Certification Environments

One difficulty experienced first with the second PWD unit and subsequently with the ground PWD trainer unit was leakage from the five-way manual valve located directly behind the front panel of the PWD. This valve is connected to the large handle on the front of the PWD that a crew member uses to select the PWD operational mode. This valve is a commercial off-the-shelf (COTS) unit that has been modified slightly to reduce its weight. The packing material around the ball valve is Polytetrafluoroethylene (PTFE) that is certified to a range of 50°F-150°F. One of the certification tests performed on the PWD is a Thermal Cycle test, which requires eight cycles of 120°F swings in temperature with functional tests performed at each temperature extreme. The PWD was tested to temperature extremes of 42°F and 162°F to avoid the critical temperatures of 35°F for initial ice formation and 200°F for fluid line overpressurization, while remaining below the PWD components' maximum temperature ratings. A leak anywhere in the system during this test is considered a failure. The original selection of the manual valve for this use was a risk because the valve is certified for a smaller range in temperature than the certification testing requires. A leak was found to occur from the manual valve at the cold temperatures during the second PWD unit Thermal Cycle testing. It was found that the PTFE packing material was contracting enough at cold temperatures to break the seal and allow a small amount of water to escape the system. Discussions with the manufacturer of the manual valve were helpful in developing the solution to the leak, which was to tighten the packing nut and compress the PTFE packing. The manufacturer explained that this action should actually be expected over the life of the unit as the PTFE cold flows over time. Tightening the packing nut did assist in reducing the leak; however, the second PWD unit eventually required a waiver to reduce the thermal test range and continue past the Thermal Cycle test.

In late 2017, the PWD trainer unit, which was built in 2008 alongside the first PWD flight unit, began experiencing a similar leak from the manual valve, except at ambient room temperatures. The PWD trainer unit experiences more handling of the manual valve than the on-orbit PWD, which typically stays in Rehydration mode. Based on the experience with the second PWD unit and the manufacturer's recommendation, the packing nut was tightened in an attempt stop the leak. The leak was ended by this action. Based on the PWD trainer unit and second PWD unit, it is anticipated that the first PWD unit may soon require a similar procedure to be performed. This development highlights a typical design dilemma of balancing a COTS component selection that appears satisfactory with a custom-designed component that is tailored for all required functions. It is recommended that if COTS components are selected, then they should be subjected to the same rigorous component testing as custom components to ensure their durability. Selecting materials with an eye for longevity can help prevent potentially large issues from occurring by designing them out of the system as much as possible.

C. Filter Orbital Replacement Unit Life Extension

Up until 2016, the PWD Filter ORU was certified to deiodinate 4000 lbm of water sourced from the PWB. This limit was set by a certification test performed in 2005 to extend the life of the generic Activated Carbon/Ion Exchange (ACTEX) filter, which NASA uses in many applications, to 4000 lbm from the previous 3000 lbm. The test flowed 5000 lbm of iodinated water through the ACTEX and recorded test data showed 0.00 ppm Iodine detected in the effluent during the entire test. The final test results indicated the ACTEX/deiodination filter could deiodinate up to at least 5000 lbm, and a margin of safety was applied to certify to 4000 lbs. The PWD Filter ORU throughput life is based on this test.

In 2015, the PWD project proposed repeating the test but running the ACTEX/deiodination filter to failure to determine the actual iodine breakthrough point and further extend the life of the ACTEX. Additionally, the test used similar test parameters as the 2005 test; however, the parameters were slightly modified to more closely model PWD on-orbit conditions. The ISS Program approved the test in an effort to reduce the running sustaining cost of the PWD. Extending the life of the Filter ORU helps reduce total upmass to the ISS, reduces crew time (maintenance to replace the Filter ORU within the PWD), and decreases the ground sustaining project team cost.

The source water iodine concentration used in the test was 3.5 ± 0.5 ppm I_2, 1.5 ± 0.5 ppm I^- (total: 5.0 ± 1.0 ppm I). Iodine samples were taken frequently during the test to obtain a good representation of the iodine breakthrough curve. Other parameters were also analyzed during the test. Total Organic Carbon (TOC) was required to be < 3.0 ppm, as the PWD requirement. Microbial analysis was performed for reference only. Particulate sizes were required to be < 200 µm per the PWD requirement with particulate filter attached. Water Quality standard four-parameter test for conductivity, pH, chlorides, and surface tensions was also taken.

Iodine analysis was performed using a UV-Vis spectrophotometer machine via Liquid Crystal Violet analysis. The machine was calibrated to the lower detection limit of 0.02 ppm with an error margin for this test's results of 0.01 ppm. Iodine in the deiodination filter effluent was first detected above 0.02 ppm at 3750 lbm throughput and broke through the PWD deiodination requirement of 0.20 ppm at 5900 lbm throughput. A graph of the test results can be found in the Appendix. TOC, particulates, and water quality results all remained within acceptable parameters. TOC levels varied from 0.00 – 0.23 ppm throughout the test with no trend observed. The post-test microbial analysis resulted in 13 CFU/mL. The post-test water quality analysis passed the standard four-parameter test. The post-test particulate analysis qualified for Level 100, which meets the PWD requirement even though this test's Filter ORU did not include a particulate filter (such a filter was included upstream). Additionally, no noticeable increase in pressure drop across the deiodination filter was identified during the test although the downstream pressure gage was uncalibrated (pressure drop readings were for reference only).

Based on the 2015 test, the throughput limit of the PWD Filter ORU was extended from 4000 lbm to 4320 lbm. Additional life could have been gained; however, a a sharp peak in iodine concentration at 5400 lbm was cause for concern. NASA could not identify justification to dismiss this peak as an outlier in the data. Theoretical resin capacity calculations performed of ideal capacity of the ACTEX showed that the data approximately line up with the life extension test results. The calculations did not immediately indicate that anything was amiss with the test to cause deiodination failure earlier than expected even though the breakthrough trend did not follow the breakthrough curve as closely as expected. Additionally, per the JSC Toxicology Laboratory one should not allow short-term consumption of high iodine levels assuming it would average out over a longer time. Not every crew member is sensitive to iodine; however, it is impractical to test for such sensitivity and the effects of consumption of higher iodine concentrations would not be apparent immediately. The biologically active form is iodide, which is what the total PWD iodine limit is set to protect against. Iodine is biostransformed to iodide, which is the metabolically active form. When present as iodide, no transformation is required. Iodide is toxic in quantities larger than required for nutrients. Total iodine is used in comparing with the 0.20 mg/L PWD limit.

In the future, additional life extension tests or modifications to the deiodination filter design can achieve even greater certified life. For the PWD use case, the iodide (I^-) is the limiting factor causing breakthrough while the iodine (I_2) levels remain within the instrument noise, as seen in the test results. Iodide is removed by the resin in the deiodination filter whereas iodine is removed by the carbon. Combined with the theoretical resin and carbon capacity calculations, it may be possible to adjust the ratio of resin to carbon within the deiodination filter to remove more iodide.

D. Design Assumptions – Use of the Potable Water Dispenser

Design assumptions for any hardware are important to identify at the beginning of the project so that components can be selected with appropriate cycle life to serve for the entirety of the hardware design life. The PWD design assumptions developed in 2007 and updated in 2013 are again out of date due to the continually expanding scope of the PWD support on-orbit. Over time, more organizations have requested use of the PWD for their own purposes since the PWD generally works well without major issues aboard the ISS and is a user-friendly and convenient method to acquire non-iodinated water. As a result, the usage of PWD has grown considerably beyond the original expected use.

The PWD is designed with an assumed number of hot and ambient dispenses performed per crew member per day. This assumption was determined in conjunction with the JSC Food Lab based on the number of food and drink packages expected to be consumed by the crew. The PWD also assumes a certain number of annual uses of the various operational modes and cycling of captive fasteners and helicoil inserts. From these assumptions, additional calculations are made based on the number of cycles the solenoid valves, quick disconnects, pushbuttons, and other components are expected to experience. The Filter ORU expected life (in number of days) is also estimated from these assumptions.

Over time, the scope of support that the PWD provides has expanded. For example, the NASA Flight Surgeons have directed the USOS crew to consume more water on a daily basis. The permanent USOS crew contingent has now permanently increased from three to four. Occasionally, Russian crew members will also use the PWD – this is estimated at approximately one-third of a crew member on average. Samples are frequently taken from the PWD to assess for water quality and microbial stability. Finally, a large deviation from the original design assumptions is the current support of payloads and experiments. The PWD was originally not intended to support any payloads usage; however, payloads currently can retrieve up to > 1 L of water per day and occasionally larger uses (several liters) for certain experiments. All of this extra usage of the PWD cycles the individual components much more frequently than anticipated, although sufficient margins of safety in selecting most of these components have ensured their continued function. The biggest impact has been to the life of the Filter ORU. Originally expected to last 11 months, the Filter ORU typically reaches its certified deiodination life in approximately 7 months and sometimes as few as 6 months. The resupply schedule has increased accordingly, thereby costing additional unplanned resources to sustain the PWD.

Since the crew uses a potable water dispenser frequently throughout each day, it must be designed to be user friendly and work without issues. If this is successfully achieved, it is made attractive to additional organizations who will want to take advantage of its capabilities. A liberal margin should be applied and every potential use case must be identified in the design assumptions for future potable water dispensers to scope the use of the hardware appropriately. This is particularly important for exploration missions where resupply of the vehicle cannot simply be doubled because the original design assumptions for the hardware were determined to be insufficient.

E. Pushbutton Light-Emitting Diodes

NASA has encountered an issue with the hot and ambient dispense pushbutton LEDs on both PWD flight units and the PWD trainer unit. The LEDs within the pushbutton assemblies sometimes do not illuminate when they should or will flicker when they should be steady. These LEDs provide an indication to the crew that water is ready to be dispensed and, in the case of the hot dispense pushbutton, that the water in the PWD is at the appropriate hot temperature. The LEDs also extinguish when a dispense is complete and the crew member can safely remove the food or drink package. When the LEDs fail to function correctly, the crew may inadvertently believe the dispense is complete and remove the food or drink package while the PWD is still dispensing.

An investigation into this issue on the second PWD unit identified a white substance/film deposited on the rear contact of the LED bulb. This was inhibiting proper contact with the switch stem and causing the light to fail to illuminate. This proximate cause is further reinforced by the fact that a light tap of the pushbutton cap would reestablish the connection and illuminate the bulb. A wipe was used to remove the film and the issue was resolved. Later, an investigation into this issue on the PWD trainer unit identified a brown susbstance deposited on the rear of the contact LED bulb. This marked the beginning of the contact corrosion and was more difficult to remove; however, once removed, the issue was resolved. This corrosion is likely the same issue that the first PWD unit is experiencing aboard the ISS. However, by now it is expected that the corrosion has advanced such that it will be difficult to remove. Even if the corrosion is removed, the process will have removed some of the bulb contact material. This effect is likely permanent at this stage. Insufficient moisture barrier in the LED pushbutton assembly design is likely the root cause for this issue. When the PWD was designed, no COTS options were available that met NASA's need; therefore, the pushbutton assembly is a mix of a variety of components assembled together. Lack of a complete integrated solution likely led to the occurence of this issue.

Response to the flickering LED issue on-orbit has been mixed. When asked, many crew members responded that they do not remember the LED status because they never needed to pay attention to it. Other crew members noticed the malfunctions and simply disregarded the LED indications as a result. Some crew members removed the food or drink packages before the dispense was complete based on the false indication provided by the LED. Overall, the issue was deemed not large for the crew to spend time addressing the corrosion. However, crew members are trained to pay attention to LED indicator lights. When included with potable water dispenser systems, the indicator lights should be designed sufficiently robust to function correctly for the life of the unit to avoid misleading the crew and dispensing water into the open vehicle cabin.

F. Slide Rails

Hardware installed into Expedite the Processing of Experiments to the Space Station (EXPRESS) racks aboard the ISS fit into standardized volumes called "lockers." The PWD is designed to fit into a double-size locker. The PWD chassis contains the vast majority of the PWD components and is seated into the locker in the operational configuration. Because the front interface panel of the PWD houses several switches, connections, and indicator lights, two side service panels on the chassis allow access to the electronics board and the Filter ORU. The PWD chassis is pulled out of the locker to access these panels. This is facilitated by two slide rails that attach the chassis to the locker.

The first PWD unit experienced a failure of one of the slide rails on-orbit in 2010. When the chassis was pulled out of the locker to reset a circuit breaker via a side service panel, the right slide rail locked up when attempting to reseat the chassis into the locker. The anomaly is unexplained, though the most probable cause was a foreign object that became stuck inside the slide rail. The crew was able to free the stuck slide rail; however, the decision was made to remove the slide to prevent the chance of binding again. The concern was that the slide rail would lock up while the chassis was seated inside the locker, in which case the slide rail would be inaccessible for a similar repair. As a result, the first PWD unit currently has only one slide rail installed. Engineering analysis during PWD design required the slide rails for ground handling due to its mass/weight. Investigative inspection of the slides in the PWD trainer unit confirmed that the slide rails are not needed for support in microgravity. In microgravity, the slide rails are only used as redundant alignment aids.

The slide rails were found to be more difficult to slide than expected during the biannual maintenance of the second PWD unit. No foreign debris was identified and additional lubrication was applied to assist with the sliding motion. At the time of the design of the slide rails in 2007, it was not anticipated that they would continue to be activated on the ground for several years during ground maintenance. In the future, the use of slide rails should be reconsidered due to their potential for failure. Other means of ground support equipment should be utilized, or flight hardware should be designed such that slide rails are not required for planned maintenance. If required, their use should be minimized.

G. Future Development of Biocides

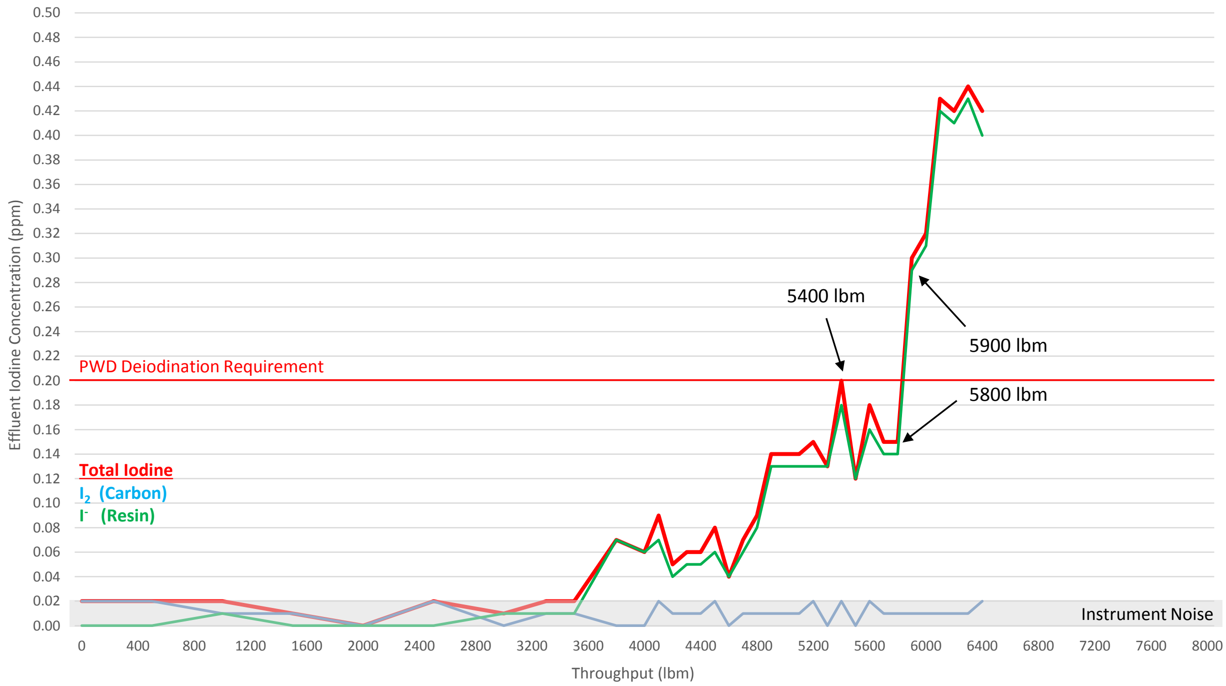
Currently, iodine is the biocide used aboard the ISS in the PWB and PWD. Although effective, this iodine cannot be safely consumed and must be removed from the water prior to crew consumption. This requires periodic replacement of deiodination filters in the PWD that remove the iodine. A consumable biocide – silver – is under consideration for future potable water systems. Using silver to manage microbial growth can reduce the complexity of the potable water dispensing system by eliminating the need for a filter to remove the biocide. Another potential disinfection system under consideration makes use of ultraviolet (UV) light. Advantages of UV disinfection include its compact size, low power consumption, and elimination of hazardous chemicals. However, this method of disinfection will likely require constant flow-through of potable water systems to maintain bacterial counts. Both silver and UV disinfection methods have the possibility of reducing the overall complexity of maintaining potable water systems and are also promising in preserving potable water system quality during long periods of stagnation for exploration vehicles.

V. Conclusion

The ISS Potable Water Dispenser has successfully served the USOS segment of the ISS since 2009. After a few initial issues with microbial contamination, slide rail malfunction, and Rehydration Station complexity, the PWD has generally performed well in supporting USOS crew members and various payloads. As of February 2018, the PWD system aboard the ISS has processed approximately 60,000 lbm of water – equivalent to more than 100,000 dispenses. Lessons learned from the first PWD unit helped to improve and enhance the robustness of the second PWD unit, which is expected to launch in the next few years in continued support of the ISS. Nine years of on-orbit operation experience and 3 years of on-ground maintenance experience of the PWD have provided valuable insight into other considerations in developing and operating potable water systems that were not envisioned during the development of the hardware. These insights and lessons learned should be useful in the design and development of potable water systems for other space vehicles and for long-duration exploration missions.

Appendix

The graph below depicts the results of the Filter ORU Life Extension test performed in 2015. Iodine concentration in the effluent was measured to determine breakthrough of the PWD deiodination requirement. The resin in the deiodination filter, which filters out the iodide (I^-), reached capacity before the carbon, which filters out the iodine (I_2). The PWD deiodination requirement is based on the sum of both iodide and iodine in the effluent.



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