Selection of a Brine Processor Technology for NASA Manned Missions

Donald L. Carter[1]
NASA Marshall Space Flight Center, Huntsville, AL 35812

Andrew F. Gleich[2]
Summer Intern 2015, NASA Marshall Space Flight Center, Huntsville, AL 35812

The current ISS Water Recovery System (WRS) reclaims water from crew urine, humidity condensate, and Sabatier product water. Urine is initially processed by the Urine Processor Assembly (UPA) which recovers 75% of the urine as distillate. The remainder of the water is present in the waste brine which is currently disposed of as trash on ISS. For future missions this additional water must be reclaimed due to the significant resupply penalty for missions beyond Low Earth Orbit (LEO). NASA has pursued various technology development programs for a brine processor in the past several years. This effort has culminated in a technology down-select to identify the optimum technology for future manned missions. The technology selection is based on various criteria, including mass, power, reliability, maintainability, and safety. Beginning in 2016 the selected technology will be transitioned to a flight hardware program for demonstration on ISS. This paper summarizes the technology selection process, the competing technologies, and the rationale for the technology selected for future manned missions.

Nomenclature

AES	=	Advanced Exploration Systems
ARFTA	=	Advanced Recycle Filter Tank Assembly
ARS	=	Air Revitalization System
BEB	=	Brine Evaporation Bag
BRIC	=	Brine Residual In Containment
EDV	=	Russian Liquid Container
ESM	=	Equivalent System Mass
FO	=	Forward Osmosis
FOBD	=	Forward Osmosis Brine Dryer
ISS	=	International Space Station
IWP	=	Ionomer Water Processor
LCC	=	Life Cycle Cost
LEO	=	Low Earth Orbit
OA	=	Osmotic Agent
TCCS	=	Trace Contaminant Control System
THC	=	Temperature & Humidity Control
UPA	=	Urine Processing Assembly
VCD	=	Vapor Compression Distillation
WRS	=	Water Recovery System

I. Introduction

The ISS Water Recovery System (WRS) Urine Processor Assembly (UPA) uses Vapor Compression Distillation (VCD) technology to recover 75% of water from pretreated urine generated on ISS. The recovery rate will be

increased to potentially 90% with the implementation of a modified pretreatment (replacing the current sulfuric acid with phosphoric acid) in 2016. Even with this improvement in water recovery, approximately 40 L/crewmember/year of water will be lost in the brine generated by the UPA. For a crew of 4 on a 3 year mission to Mars, the total water lost in this brine is approximately 440 L. This quantity may also increase depending on technologies selected for this mission (for example, use of Reverse Osmosis in the Water Processor) and system architecture that would include hygiene and/or laundry waste water. Given the upmass limitations associated with the Mars mission, personnel in NASA's Advanced Exploration Systems (AES) program have been pursuing technology development for recovering this water from the urine brine. The NASA strategic vision for exploration is to demonstrate technologies applicable to a Mars mission while the International Space Station (ISS) is operational. Although the actual Mars mission is still many years away, it is important to begin the development and evaluation process now to insure the technology is ready when the flight hardware program begins.

The specific mission architecture for a Mars mission has not been defined. Therefore, the specific brine composition is unknown. The most likely brine will be from processing crew urine, consistent with the ISS architecture. However, as mentioned previously, Reverse Osmosis technology may produce a brine from processing crew latent and urine distillate. Another possibility is waste from hygiene and laundry, which would introduce additional complexity associated with surfactants. Since no surfactants for hygiene or laundry have been identified, there was uncertainty with evaluating a brine processor technology for these applications. Because of the uncertainty associated with the specific mission architecture, the AES development program for a brine processor technology focused on water recovery from urine brine. Urine brine will be the most concentrated of the candidate solution and is also well understood. Furthermore, it is considered a worst-case solution because of the corrosive nature of the brine. This is because of the pretreatment required to process the urine through the urinal and UPA, which includes chromium trioxide (oxidizer) and an inorganic acid (sulfuric for the current pretreatment and phosphoric for the new pretreatment) to drive the pH to approximately 2.0.

A technology down-select was scheduled for October 2015 to evaluate the various candidate technologies and identify the optimum technology for evaluating on ISS, as well as the merit for funding other competing technologies as a potential backup plan. The brine composition and critical parameters were based on the ISS system architecture. The primary interface for the brine processor is the UPA brine tank, named the Advanced Recycle Filter Tank Assembly (ARFTA), which must be emptied of 22 L of brine approximately every 3 weeks. As such, each brine processor technology would need to be capable of processing brine at a rate of 22 liters in 22 days in a continuous microgravity environment over an operational period of 3 years (expected duration of a Mars mission). The brine composition would be based on 85% recovery of crew urine pretreated with chromium trioxide and phosphoric acid. Proposed technologies must demonstrate a basic level of technical maturity and provide proof that continued development will produce a system ready for installation on the ISS as early as 2017. The proposed systems must display proper technical development of each technology, along with the operational characteristics and the contingency factors for the system. Each system should be defined down to a component level from a technical perspective. The operation of the system must be defined in terms of normal operation, maintenance, and failure modes. The entire mission duration must be accounted for including consumables and credible failures.

There are several other resources and constraints that were also considered in this technology assessment. First, the brine processor may vent gas associated with the water recovery process directly to the cabin assuming the gas does not contain compounds harmful to the ISS crew. This approach relies on the ISS Trace Contaminant Control System (TCCS) and Temperature and Humidity Control (THC) system to process trace containments and condensate. For technologies that do vent, the gas composition must be characterized for ISS engineering personnel to assess impacts to crew and systems' health. ISS resources available for each technology also include power, cooling, and crew time. Although no direct limit has been placed on these resources, they must be quantified for the technology assessment. Finally, crew time for the technology down-select will not include the time required to drain the brine tank into the brine processor (since that is crew time already accounted for with UPA operations), but all other tasks required by the crew to set up the brine processor for each operational cycle must be documented.

II.   Criteria for Technology Down-Select

The following criteria were considered by a committee of NASA personnel for each candidate technology. This information was first provided in a report by each Principal Investigator, and then presented to the committee at the technology down-select to allow for discussion. The committee represented personnel from various NASA centers

and different backgrounds to insure a fair but critical assessment of the various technologies. Changes were made to each data package during the presentation as required to insure consensus among the committee and the Principal Investigator. This ensured that the documented information for each criteria were directly comparable between the competing technologies.

- System Mass/Volume
- Power Requirements
- Reliability
- Complexity
- Safety
- Interface Definition
- Production Rate
- Water Recovery Rate

- Cooling Requirements
- Crew time requirements
- Acoustic environment
- Open Technical Issues
- Maintenance frequency
- Materials compatibility
- Mass of consumables & spares
- History of technology development

Of these criteria, the most critical included total mass, reliability, safety, and open technical issues. Total mass is critical because of the limitation for launch mass and resupply associated with future missions, including a Mars mission. Similarly, the candidate technologies need to exhibit reliable functionality, meaning the concept was simple and implemented components that were proven to operate for extended duration without failure. Though safety is always a significant issue, it is of additional concern with brine processing because of the toxic nature of the brine. Each technology had to show at least two levels of fluid containment throughout the process, including planned and unplanned maintenance. Finally, open technical issues were thoroughly evaluated to insure there would not be a significant ongoing development effort for the selected technology during the flight hardware program.

The technology down-select did not use a single variable evaluation method, such as life cycle cost (LCC) or equivalent system mass (ESM), but instead used a holistic method based on an engineering assessment of quantitative (e.g., system mass) and qualitative (e.g., reliability) criteria. Each technology data package provided a detailed discussion on each of the criteria to aid the evaluators in the development of an overall understanding of the viability of the technology. Though this approach is not purely quantitative, it is believed to be a more accurate method that provides the evaluators with the flexibility to use engineering judgement to appropriately weigh the value of qualitative criteria.

III. Candidate Technologies

The following technologies were presented at the technology down-select. Provided is a summary of the primary mechanism of water recovery, a description of the major system components, and the process to operate each system.

A. Forward Osmosis Brine Dryer (Ames Research Center)[1]

The Forward Osmosis Brine Drying (FOBD) system uses two processes to recover water from the urine brine. The first part of the system uses a membrane-based process where the osmotic potential between two fluids of differing solute/solvent concentrations is equalized by the movement of solvent (water) from the less concentrated solution to the more concentrated solution. In the FOBD system, the urine brine is placed on one side of a membrane and a salt-water solution called the osmotic agent (OA) is present on the other side. The proposed osmotic agent is a lithium chloride solution; however, any solute could potentially be used as long as it can produce an osmotic pressure that is higher than that of the brine. As water moves across the membrane, the OA is diluted and excess water must be removed to continue recovering water from the brine.

The second part of the system uses an evaporative process to recover the water from the OA before returning the OA to the first process step. The proposed system utilizes a heat exchanger consisting of a metal block heated to 135°C with a V-shaped groove through which the OA passes. A hydrophobic cover allows vapor to pass through the heat exchanger and into the cabin while the remaining liquid is retained within the heat exchanger. This part of the system has not been demonstrated thus far and would require further development.

The FOBD system was proposed in three different configurations, one which utilized a forward osmosis (FO) bag large enough to hold the entire 22L of brine, one configuration utilizing an EDV for intermediate brine storage, and a final configuration which utilized an intermediate brine storage and a larger volume of OA. The second configuration

is the one discussed here as it most closely resembled what has been studied in the lab and was discussed during the technology down select meeting in greatest depth. A simplified flow diagram of the FOBD system is shown in Figure 1.
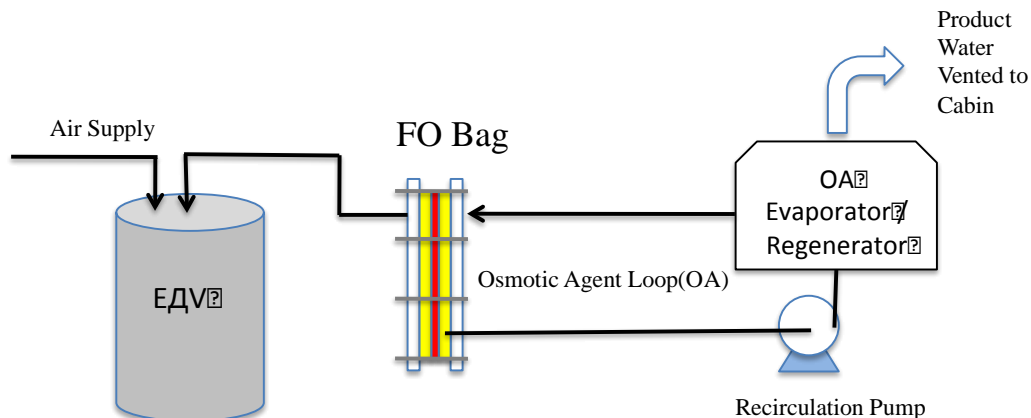

Figure 1: Simplified Flow Schematic for the FOBD System

The FOBD system in Figure 1 consists of four primary parts. The EDV is used as an intermediate storage for the brine during the processing period. The FO bag holds the brine being processed and contains the membrane which separates the brine from the OA. The recirculation pump proposed is a two-head peristaltic which both pumps OA from the FO bag to the evaporator and returns the OA from the evaporator to the FO bag. The evaporator consists of the V-shaped heat exchanger with heating element. The full system provided in the proposal includes several temperature and pressure sensors which automatically control the system during processing of the brine. The FOBD maintains multiple layers of containment throughout the processing of brine. The FO bag itself is the primary layer of containment which relies on the semi-permeable membrane to maintain separation between the brine and the OA. A further layer of containment is provided by an additional bag which contains the FO bag and is connected through the no-drip quick disconnects used to fill the FO bag. The final layer of containment is the FOBD housing itself which contains hydrophobic filters for inlet and outlet air.

To operate the FOBD system multiple steps must occur during processing. The brine is transferred from the ARFTA to an EDV and attached to the FO bag. The FO bag is preloaded with OA and then filled with brine. The recirculation pump is started and power is applied to the heater. Once per day the FO bag is filled with new brine from the EDV. Every seven days a new FO bag is installed as a precaution due to wear down of the FO bag membrane. The OA is transferred from the old bag to the new bag to conserve mass. The old FO bag containing concentrated brine solids is transferred to a storage container for the remainder of the mission. During processing, additional OA may need to be added to the system to account for losses within the system.

B. Brine Evaporation Bag (Ames Research Center)[2]

The Brine Evaporation Bag (BEB) System utilizes a combination of a semi-permeable membrane, heat and vacuum to separate the water from the remaining brine. The basic mechanisms for water recovery are to boil the brine within a plastic container at reduced pressure. The membrane used in the BEB is permeable to water and trace amounts of other components, but impermeable to liquid and solids. Once the water vapor has been extracted it is allowed to cool slightly and returned to atmospheric pressure which causes condensation. The membrane itself consists of two membrane layers which helps ensure that contaminants are not released to the environment.

The BEB operates as a batch system with the initial 22L held within a single container and the final product water stored in an EDV for later purification. The BEB System is composed of three primary parts, the BEB itself, the BEB Evaporator and the vacuum pump. The BEB is a cube shaped plastic container which holds the brine during processing and has a membrane installed in one wall. The membrane allows water in the vapor phase to be removed while keeping the remaining liquids and solids contained. The BEB Evaporator is a solid box which provides both the structural support for the BEB and the heating required to create boiling of the brine within the BEB. The entire BEB system is maintained at a negative partial pressure by the vacuum which is also responsible for condensing the water vapor after separation. The system layout, process controls, and operating procedure for the BEB system are displayed in Figure 2.
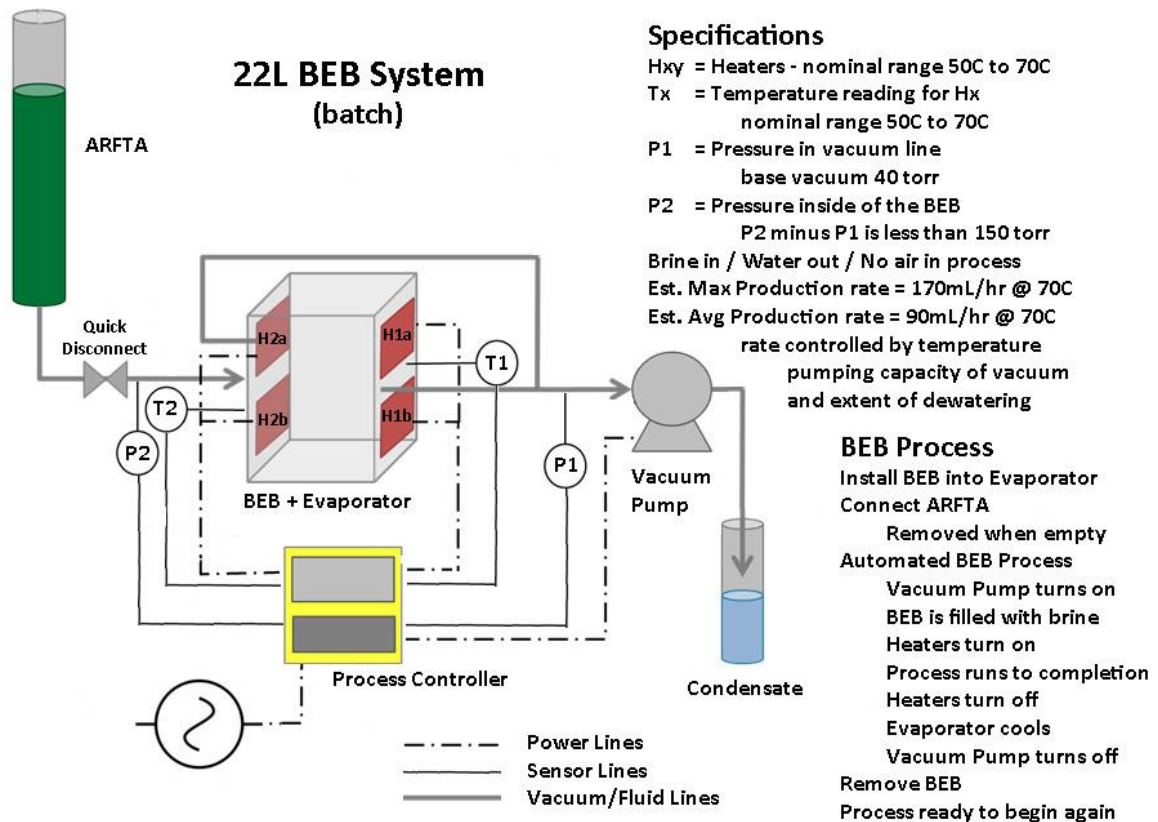
Figure 2: BEB System schematic including process controls and operating procedure

The BEB is filled directly from the ARFTA on the WRS before being transported to the BEB evaporator. Heat is applied to the BEB evaporator through patch heaters. A process controller is used to maintain the appropriate system temperature and pressure during the evaporation process. The condensate from the vacuum pump is stored in an EDV until the end of processing. Containment of the brine is maintained throughout the operation of the process through multiple layers of containment. The BEB itself provides the primary level of containment for liquid and solid components. The BEB evaporator provides additional containment through the use of seals and negative pressure. The final level of containment is achieved by operating the BEB system within a glovebox onboard the ISS.

The BEB system is operated in a batch mode, with all of the initial brine being collected in a single BEB and all of the recovered water being collected in an EDV as a liquid. To operate the system the ARFTA is connected directly to the BEB using a transfer hose and a quick disconnect port which passes through the BEB evaporator housing. Once the transfer is complete the process can be started by turning on the vacuum pump and applying power to the heaters in the BEB evaporator. The evaporation process is automated and shuts down once the evaporation is complete. Upon shut down the water is emptied out of the EDV into the WRS for further purification. The BEB which now contains the brine solids is removed from the BEB evaporator and transferred to a storage container for the remainder of the mission.

C. Capillary Brine Residual in Containment (Johnson Space Center)[3]

The Capillary Brine Residual in Containment (CapiBRIC) system utilizes the mechanism of air evaporation to recover water from the urine brine. The unique feature to this system is the use of capillary action for the infill and primary containment of the brine, rather than a membrane or physical barrier. The designed proposed uses a tray with radial wedges, similar in shape to an apple core to contain the brine for drying. The size and shape of the wedges have been designed to ensure the brine remains contained in a microgravity environment. The possibility of shock accelerations from activities such as docking/undocking, and crew interactions were factored into the design of the

tray. These considerations cannot be tested in a normal laboratory environment due to the constant 1G acceleration on Earth, instead drop tower testing has been used to confirm the viability of this containment mechanism.

The CapiBRIC system utilizes a semi-batch process to dry the 22L of brine. The drying trays are not sized to hold the entire 22L of brine. Instead a continuous infill of the drying trays is used throughout the process to maintain liquid level in the trays. An intermediate storage tank is used to hold each batch and capillary action controls the liquid level in the trays. This infill process had not be demonstrated during actual brine drying at the time of the technology down select. The major components for the CapiBRIC system are the intermediate brine storage tank, the capillary evaporators, the fan and heater. Figure 3 displays a system schematic for the CapiBRIC system.
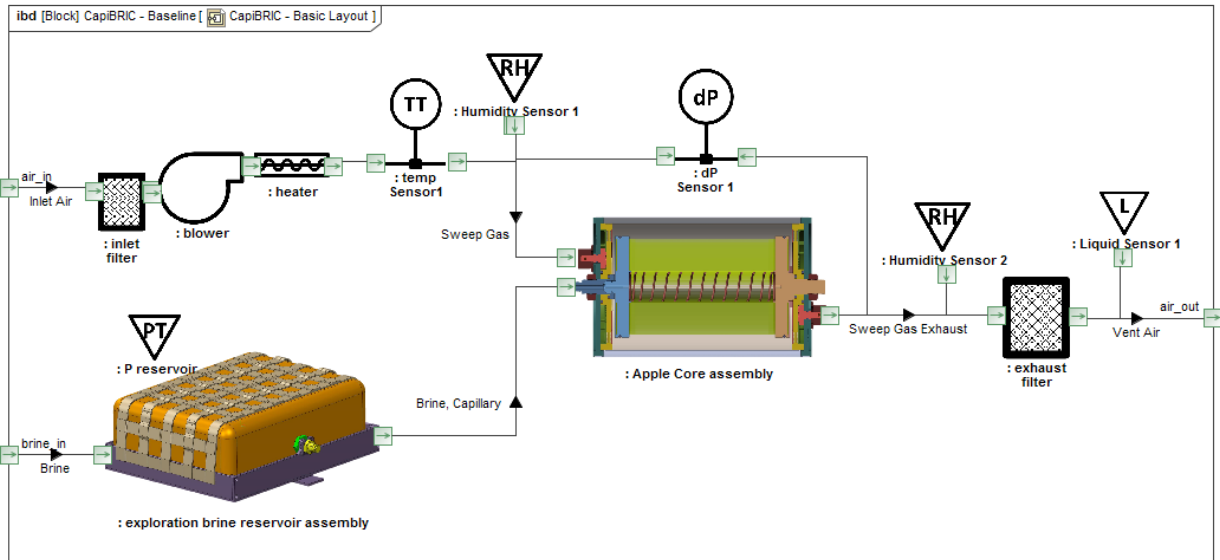

Figure 3: System Schematic for the CapiBRIC system including support equipment and controls

A fan is used to pass cabin air through the system, across the drying surface and back out into the cabin to affect the drying process. A heater is included in the current design to accelerate the drying rate, but may not be necessary in future configurations. The water vapor from the system is released directly to the cabin where it is recovered by the Air Revitalization System (ARS). Temperature and pressure are both monitored throughout the process and used to identify process upsets. An inlet filter prevents ingestion of debris from the cabin and a hydrophobic filter at the outlet prevents the release of liquid water to the cabin. Containment of the brine is maintained within the CapiBRIC system on multiple levels. Primary containment is achieved by the capillary forces within the capillary evaporator itself. Additional containment is achieved by the inner and outer walls of the capillary evaporator along with dual hydrophobic filters on the inlet and outlet of the capillary evaporator. A final level of containment is achieved by hydrophobic filters at the inlet and outlet of the system and an inline moisture sensor at the outlet of the system.

The CapiBRIC system is operated in multiple steps. Initially a set of 6 capillary evaporator assemblies are installed in the system. The reservoir assembly is then filled from the ARFTA and transported to the CapiBRIC system. Once installed, the capillary evaporators are allowed to fill through capillary action until equilibrium is reached. The fan is turned on to allow airflow across the brine surface and the heater is turned on if necessary. As water evaporates, the level in the evaporators is maintained by capillary action until all the brine is emptied from the reservoir. Once the reservoir is empty and sufficient evaporation time has been provided, the system can be shut down. The capillary evaporators containing the remaining brine solids are removed from the CapiBRIC and stored in a container for the remainder of the mission.

D. Ionomer Water Processor (Paragon Research Company)[4]

The Ionomer Water Processor (IWP) relies on a double membrane and active convection to separate water from the bulk brine through evaporation. The membrane covers the entire surface of the bag and is designed to allow only air, water vapor, and trace amounts of other components through both layers of the membrane. The IWP utilizes the forced convection of spacecraft cabin air to evaporate purified water from the brine. The air is passed over the outside

of the evaporation bladder where it picks up humidity before being released directly to the cabin. An inline heater is used to accelerate the drying process.

The IWP system consists of four main components along with several pieces of support equipment. A general system schematic is displayed in Figure 4. The evaporation bladder itself contains the entire 22L of brine and is constructed of the double walled membrane along with a quick disconnect fill port in its side. The evaporation bladder is contained within a flexible enclosure called the detrusor. In anatomy, the detrusor is the muscle in the mammalian bladder that allows the bladder to fill and be emptied of urine. In the IWP, the detrusor has the dual function of providing a level of containment and maintaining a constant flow channel for the convective air by collapsing as the brine is evaporated. The other components are the fan which provides motive force for the air, and the heater which accelerates the evaporation process. The fan is placed up stream of the IWP to create a slight negative pressure.
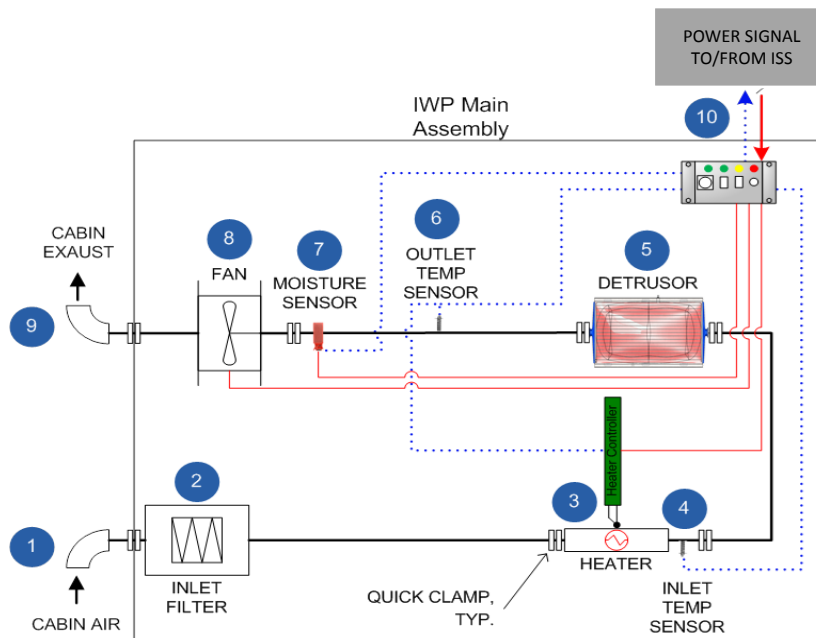

Figure 4: System schematic of the IWP including process controls and support equipment

Other notable components in Figure 4 are the inlet filter which prevents the ingestion of debris or moisture to the system. The inlet and outlet temperature sensors are used to control the power to the heater and to determine the conclusion of drying the brine. The moisture sensor is used as a final check to prevent brine leakage from the system to the cabin. Brine containment is provided through multiple layers. Each layer of the double membrane is constructed of a different material and acts as both a primary and secondary level of containment. The detrusor acts as an additional level of containment. The final level of containment is provided by the moisture sensor along with inlet/outlet hydrophobic filters.

The IWP is operated by first installing a new evaporation bladder and closing the system. A transfer hose is connected directly from the ARFTA to the IWP to minimize exposure to the brine. Once filled, the crew starts the system by turning on the fan followed by the heater. Safety controls prevent the heater from being turned on unless air flow is detected. The system is designed to maintain an outlet temperature of 35°C. The inlet and outlet temperatures are monitored throughout the drying process. Once the temperatures have reached an equilibrium the drying process is complete and the system can be shut down. After shut down, the evaporation bladder containing the remaining brine solids is removed from the IWP and stored in an air tight container for the remainder of the mission.

IV. Evaluation Summary

The quantitative data for each technology assessment was compiled into a summary spreadsheet to support a comparative assessment of the various technologies.

Table 1. Summary of Quantitative Data

Technology	CapiBRIC	IWP	BEB	FOBD
System Mass	17.3 kg	14.1 kg	52.8 kg	67.8 kg*
System Volume	0.11 m3	0.15 m3	0.14 m3	0.16 m3
System Power	134 W 57 kw-hr/cycle 3.8 kw-hr/kg H2O	142 W 36 kw-hr	361 W 69 kw-hr	190 W 100 kw-hr/cycle 4.6 kw-hr/kg H2O
Total Mass	411 kg 0.57 m3	53 kg 0.71 m3	85.7 kg 0.08 m3	112 kg* 1.2 m3
Water Recovery	98%	>80%	95 - >99%	92%
Production Rate	2 L/day	1.3 L/day	2.8 L/day	1 L/day

*does not include mass for prefill or makeup osmotic agent

The System Mass/Volume/Power refers to the mass, power, and volume required to operate the system at the defined interfaces. The Total Mass adds the mass for consumables and spares expected to support a 3 year mission. Water Recovery refers to the % of water that could be removed from the urine brine, and was based on actual ground test data. Production Rate is the rate at which the technology would generate water, whether as a liquid or in the vent gas. The quantitative data indicated IWP provided the better technology, as it was at or near the best value for each criteria. Each of the other technologies had at least one criteria that was an issue (mass for FOBD, power for BEB, and total mass for CapiBRIC). However, the basis for this data also provided room for improvement for these technologies if specific technical issues could be resolved. For example, to meet the required dual containment for safety, CapiBRIC required replacement of its consumable within a sealed chamber. This additional level of containment significantly increased CapiBRIC's consumable mass. If a more elegant design solution could be achieved that eliminated the sealed chamber, CapiBRIC is more competitive in these quantitative criteria.

Limited samples of the vent gas from each technology were taken during representative ground tests and analyzed by the JSC Environmental Chemistry Laboratory to provide input for the technology down-select. The reported data was reviewed by NASA personnel[5] to provide an overall assessment of the impact of this vent gas on ISS air quality. This assessment determined that IWP provided the vent gas with the lowest contaminant load, on the order of 14 crew equivalents. The better performance for IWP is expected to be due to the use of the Nafion membrane to reduce the release of volatile organics into the vent gas. CapiBRIC and BEB were on the order of 40 crew equivalents, and FOBD was approximately 1370 crew equivalents, presumably due to the method used to evaporate water using the V-shaped groove evaporator. Based on this analysis, all technologies may require further treatment to allow release of the vent gas into the ISS atmosphere.

Crew time was a challenging parameter to provide a consistent estimate between the various technologies. This difficult was due to the relative immaturity of each technology and the anticipated maintenance required by the crew. Based on the technology design, the IWP and the BEB are expected to require less crew time compared to the CapiBRIC and FOBD. This advantage is based on the fact that IWP and BEB each maintain the waste product within a bag that can be readily replaced to initiate a new process cycle. However, additional design features may be implemented with CapiBRIC and FOBD to improve their maintainability and therefore the required crew time. As such, crew time was not a differentiating factor in the technology down-select.

As stated previously, safety is a critical parameter for this technology due to the toxicity of the urine brine. As such, it was treated as a pass/fail criteria for the technology down-select. If a technology could not show two levels of viable containment throughout the process (including standard and off-nominal maintenance), then it would not have received further consideration. Fortunately, all technologies provided a design that showed containment of the hazardous fluid was maintained, though in some cases there were concerns about the robustness of the containment. Those specific concerns are discussed in the following section as open technical issues.

V. Reliability and Open Technical Issues

The open discussion in the technology down-select provided the opportunity to identify reliability issues with each technology, as well as technical issues that could prevent the technology from functioning properly in micro-gravity. This factor was highly critical in the technology selection, since system reliability is considered to be of utmost importance for life support systems in general, and specifically for a Brine Processor technology. Furthermore, open

technical issues will result in increased cost toward hardware delivery, and therefore an accurate definition of these issues was necessary to quantify to the extent possible the remaining technical risk associated with delivery of the competing technologies. A summary of the most critical issues is provided below for each technology.

A. FOBD

The Forward Osmosis technology is known to work in micro-gravity based on previous flight experiments. However, the evaporator concept proposed at the technology down-select is unproven and may not function in micro-gravity. This evaporator requires the effluent of the FO membrane to be poured into a v-groove on a heated metal plate for evaporating the water. This process creates a measurable risk of mineral precipitation in the v-groove. Furthermore, a two-stage peristaltic pump would be used to balance the flow rate between the evaporator and the FO process. This is not considered reliable and as such the technology committee at the down-select recommended FOBD develop another drying process other than the v-groove evaporator.

Another critical issue with FOBD is maintaining the lithium chloride (LiCl) solution as the osmotic agent. The LiCl will be lost over time in the brine and during replacement of the FO bag, as well as precipitation and dilution during long-term storage. Since the specific quantity of LiCL that is lost is unknown, it is not known how to determine the quantity that must be added as make-up solution to maintain the FOBD function.

Finally, the FO membrane will allow urea to pass into the loop containing the osmotic agent. Urea will decompose into ammonia, which will be evaporated into the vent gas. Ammonium may also accumulate and precipitate in the loop. Long term testing of the FOBD would be required to determine the significance of this issue.

B. BEB

The BEB process is a relatively simple process in which the brine is boiled using vacuum pressure and heating, allowing the water vapor to pass through a ePTFE membrane. The primary technical concerns with this technology include scaling the manufacturing process and operational verification to a 22 L bladder, since ground tests were performed with a 3 L bladder. A larger bladder may require additional vacuum ports to maintain the evaporation process. Furthermore, the heating process my not maintain sufficient continuity with a larger bag.

Next, proper filling of the bag in microgravity without pressuring the bladder is a technical issue. The Principal Investigator emphasized that pressurizing the bag would tend to force brine through the ePTFE bladder. This is a risk because the fill process must be done slowly to insure gas can be removed by vacuum while the brine wets the polyurethane bag.

Another technical issue with the BEB is that free gas will form as water is evaporated out of the brine. The free gas will introduce thermal variants, since the external heaters are maintained on a set duty cycle. This issue may require a thermal model to show the worst-case free gas volume will not create a hazardous thermal environment.

Finally, there was uncertainty associated with the formation of condensate at the effluent of the vacuum pump in the drying process. This occurs when the water vapor pumped by the scroll pump reaches ambient pressure and cool from the 70°C operating condition in the BEB. This empirical observation needs to be verified analytically to insure the condition is repeatable during microgravity operation. In addition, further testing may be required to verify the scroll pump can reliably pump two-phase flow, including the condensate observed.

C. CapiBRIC

The CapiBRIC was a challenging technology to evaluate because its primary function (capillary flow) actually requires a micro-gravity environment. In 1-G, CapiBRIC will not work because gravitational forces will overcome the capillary forces required to distribute the brine. As such, limited technology demonstration could be presented to conclude this concept would work in micro-gravity.

There are several open technical issues associated with the capillary fluidics. The primary concern is distribution of the fluid onto the evaporator using capillary flow in micro-gravity. Specifically, would the fluid momentum overwhelm the surface tension effect, allowing some brine to become free-floating? Also, any pressure transients associated with the feed reservoir (most likely an ambient pressure plastic bag) must not impede capillary flow as the fluid is distributed onto the evaporator. Finally, pressure drop associated with the air flow may also impact fluid distribution and/or retention on the evaporator, depending on the actual pressure at the evaporator relative to the pressure provided by the feed reservoir.

Next, this technology may be susceptible to free gas. The flow passages from the feed reservoir into the evaporator will have limited cross-sectional area. Though capillary flow will obviously provide some pressure drop, it may not be sufficient to overcome the bubble point required to push free gas through the passageway, therefore preventing the brine from reaching the evaporator.

Another issue included maintaining capillary flow throughout the drying process. The primary concern is that the formation of precipitates (as the brine dries) may impede capillary flow at the outer edges of the evaporator, which might also prevent drying of the brine in the center of the evaporator. This issue would likely be resolved by proper evaporator design, to insure fluid distribution precluded this effect.

Finally, a mechanical issue was addressed related to sealing of the evaporator at the end caps. The design discussed at the technology down-select did not provide sealing at the end caps, which would allow brine to leak. This is a potentially complex sealing mechanism and must be addressed before a flight demonstration can be pursued.

D. IWP

The IWP has completed a Phase I and II Small Business Innovative Research (SBIR) program, and as such has received significant development to address technical issues. One open issue is leakage of the ePTFE due to embrittlement during the heat seal process. This issue has also received development funding through a small Phase II SBIR program and is not expected to be an issue for a technology demonstration program.

Another open issue is designing a feed port on the side of the bladder (compared to the current design where the feed port is centered on the top of the bladder). This modification is desired for packaging membranes for launch and storage.

Next, further development is required for the detrusor, which is used to maintain effective air flow across the bladder during the drying process. Further development with the supplier is required to complete the detrusor design and develop a reliable and repeatable manufacturing process.

Finally, the IWP bladder is also sensitive to overpressurization during the fill process. Based on conversations with the Principal Investigator, it is unlikely this can be resolved through the development of a more robust bladder design. Instead, a systems approach must be implemented to insure the bladder is never overfilled during operation.

VI. Conclusion

Based on the data provided at this technology down-select, the IWP technology developed by Paragon Research Company was selected for a technology demonstration on ISS. The IWP provides the lowest technical risk based on the review performed at the technology down-select, and also provides the best overall technology for the quantified criteria, including total mass. This effort to fly IWP as a technology demonstration is now funded by NASA with a scheduled hardware delivery in January 2018. The CapiBRIC technology was also selected to receive additional development funding through the AES program due to its potential to be a more advantageous technology if the open technical issues can be resolved. This technology has also been funded for a small-scale and short term technology demonstration on ISS to evaluate the concerns with operation in micro-gravity.

Acknowledgments

References

[1]Flynn, M. and H. Shaw, Forward Osmosis Brine Dryer Data Package in Response to RFI for Brine Processor Technology Down-Select, submitted in October 2016

[2]Delzeit, L., Brine Evaporation Bag Data Package in Response to RFI for Brine Processor Technology Down-Select, submitted in October 2016

[3]Callahan, M. and M. Sargusingh. Capillary Brine Residual in Containment Data Package in Response to RFI for Brine Processor Technology Down-Select, submitted in October 2016

[4]Kelsey, L., and B. Finger, Ionomer Water Processor Data Package in Response to RFI for Brine Processor Technology Down-Select, submitted in October 2016

[5]Perry, J., email correspondence, "RE: Brine Processor Down-Select – Source Contamination Control Quick Look", 27 October 2015