

Development and Testing of a New Partial Gravity Urine Processor Design and Urine Pretreatment

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The Planetary Urine Processor (PUP) is a urine distillation system for lunar or planetary applications, taking advantage of local gravity for phase separation as well as the movement and storage of waste feeds and distillate. The PUP utilizes a stationary evaporator with an integrated disposable bag to process urine and capture remaining precipitates. This system aims to increase water reclamation percentage to greater than 96%, reduce resource requirements, and enhance reliability and maintainability due to lower system complexity over the existing water recovery system on the International Space Station (ISS). This paper focuses on the hardware development, testing efforts, and the associated urine pretreatment development work.

Nomenclature

BVAD	=	Life Support Baseline Values and Assumptions Document	*UPA*	=	Urine Processor Assembly
CM	=	Crew member	*W*	=	Watts
COTS	=	Commercial off the shelf	*WPA*	=	Water Processor Assembly
ECLSS	=	Environmental Control and Life Support System			
H_2O_2	=	Hydrogen peroxide			
hr	=	Hour			
in^2	=	Square inch			
ISS	=	International Space Station			
kWhr	=	Kilowatt hour			
L	=	Liter			
lb	=	Pound			
mg	=	Milligram			
mil	=	One-thousandth of an inch			
min	=	Minute			
ml	=	Milliliter			
mmHg	=	Millimetres of mercury			
µS/cm	=	Microsiemens per centimeter			
ORU	=	Orbital Replacement Unit			
PB	=	Precipitates Bag			
PUP	=	Planetary Urine Processor			
PPM	=	Parts per million			
PTFE	=	Polytetrafluoroethylene			
TOC	=	Total organic carbon			

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I. Introduction

THE existing water recovery system on the International Space Station (ISS), the Urine Processor Assembly (UPA), was designed for operation in microgravity. It is therefore complex, heavy, and any maintenance is limited to the orbital replacement unit (ORU) level. It is also limited to around 87% water recovery due to the need to avoid precipitates in the system. Consequently, long duration space missions to planetary bodies are unfeasible with the current technology alone due to the amount of water needed to sustain the crew or the need for a water resupply. Several technologies are therefore currently being investigated by NASA to determine the best method to recover wastewater on long duration missions to planetary bodies. One such technology being considered is the Planetary Urine Processor (PUP) designed and tested at NASA's Marshall Space Flight Center (MSFC).

The PUP was designed to utilize the local gravity on planetary bodies to reduce system complexity and mass, increase reliability and maintainability, and increase the water recovery rate over the UPA. This paper focuses on the PUP's initial designs, testing and data, and associated urine pretreatment studies as a feasible planetary wastewater processing technology.

II. Planetary Urine Processor Design Concept

Table 1 below details the initial baseline loads that were used to develop the PUP design requirements and concept design. The initial design parameters were derived from the ECLSS BVAD, NASA-STD-3001 and CONOPS defined under the Artemis Base Camp. These include considerations such as:

- Penalties for up/down mass to/from lunar or planetary habitat
- Recovery efficiency for ISS UPA is approximately 87% and is limited by brine solids concentration in order to prevent precipitation in the recycle loop
- Nearly 100% water recovery is desirable for lunar or planetary surface habitats. Lower recovery necessitates more water which adds volume and mass.
- Anticipate an increased duty cycle over ISS UPA due to lower processing rate and smaller size.
- Operation at higher temperature may have power/size advantages but could be offset by increased ammonia generation.

Table 1. Initial Design Loads/Requirements

	Units	Value
Urine	lb/CM-day	3.31
Flush	lb/CM-day	1.09
Recovery Efficiency	%	>96
Total Dissolved Solids	mg/L	43300
Urea	mg/L	23300
Pretreat Formulation	mL/Flush	3.30
# of Crew	-	4
Duty Cycle	%	>60
Operating Temperature	^{o}C	~38

Designed to sustain a crew of four on a planetary mission, the PUP (Figure 1) is proposed to operate as a daily 'batch mode' vacuum distillation process comprised of three main components: a stationary evaporator with external resistance heaters, an internal disposable Precipitates Bag (PB), and a vacuum pump. At the start of a process run, H_2O_2-pretreated urine is pumped into the evaporator to be processed under vacuum. A vacuum pump provides the required vacuum for the distillation process and the two-phase fluid flow of distillate and non-condensable gases to the downstream distillate tank. External heaters adhered to the evaporator are used to drive the distillation process. Local gravity is utilized for the phase separation of gasses, including water vapor, during the vacuum distillation process. The PB, installed inside of the evaporator, contains the pretreated urine during the distillation process. As the volume of urine in the PB is processed, heavier precipitates and non-volatile pretreat solution collect at the bottom of the bag. The PB is designed to be disposed of and replaced after 30 days of processing, when it has reached its limit of collected precipitates. Final disposal of the PB is to be determined per Planetary Protection Protocols.

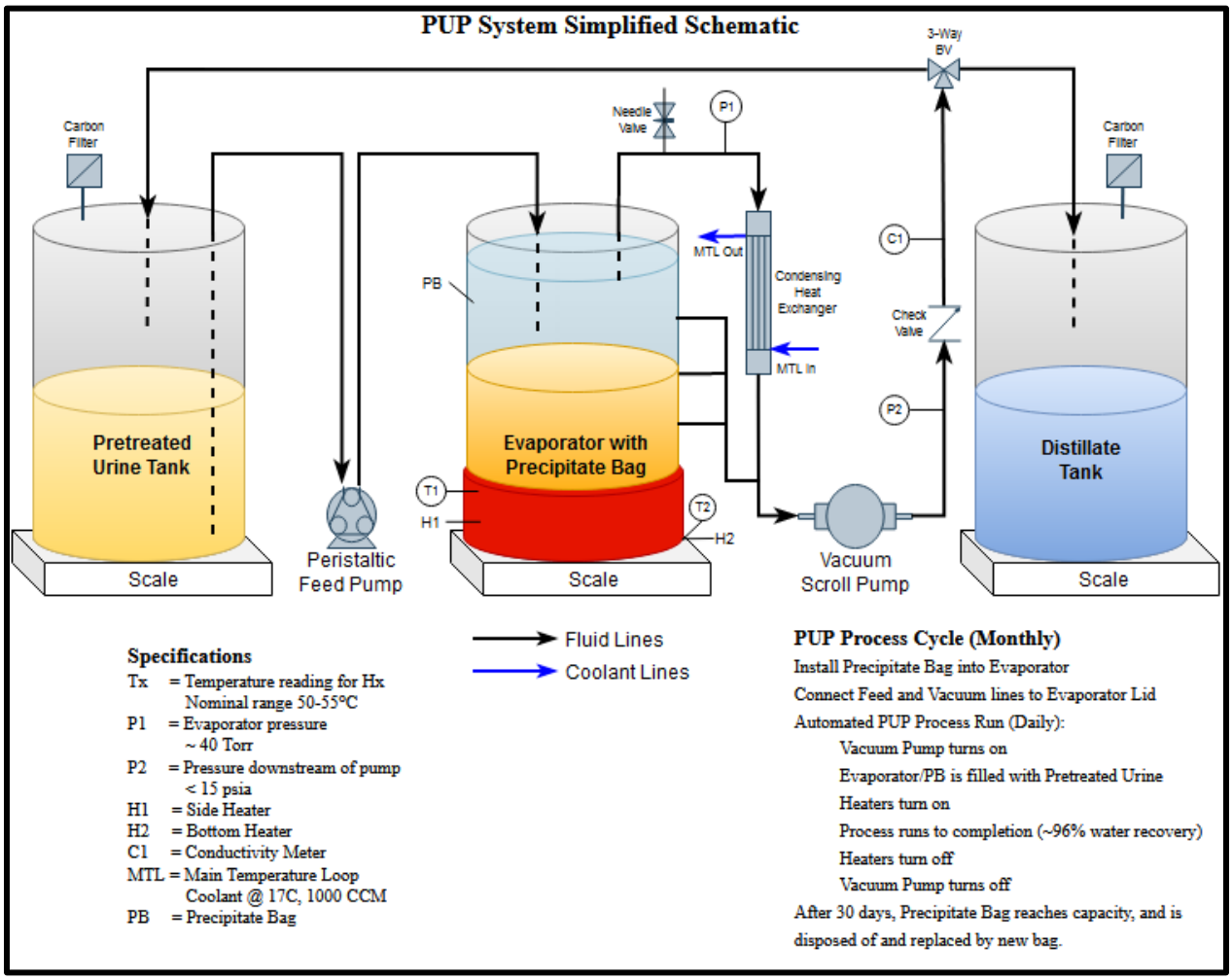


Figure 1. Schematic of the PUP System

III. Development of the Planetary Urine Processor

Development of the PUP has progressed from initial concepts and designs to proof-of-concept testing and subsequent process improvements.

A. H_2O_2 Urine Pretreatment Testing

A urine pretreatment study was conducted as part of the PUP development effort. The goal of this study was to find an effective, less toxic, and low mass urine pretreatment alternative to the current pretreatment used on ISS. Currently, a mixture of chromium and phosphoric acid is used on ISS to stabilize the collected urine. Although this has been a necessary urine pretreatment, or stabilization, approach for the current state-of-the-art microgravity based urine processing, use of more green and less corrosive pretreatment should be further explored for future partial gravity water recovery architectures.

1. Alternative Urine Pretreatments Downselect

A study was conducted focusing on one four alternative pretreatment stabilizers. Initial tests included four pretreats: hydrogen peroxide, sodium permanganate, Bronopol, and 1,2 dibromo-2,4-dicyanobutane (DB-DCB). Like that of the phospho-chromium based pretreatment as found on the ISS, the primary purpose of a stabilizer is for microbial control. This is achieved mostly due to the strong oxidizing agent (i.e. hexavalent chromium) but also the use of an acid to drop the pH or use of a bactericide that enhances effect and creates an inconducive environment for healthy biological activity[1,2]. The four choice pretreatments here were selected based on expected low mass requirement for effectivity in microbial control being less than 5 g/L-urine. For reference, the use of oxone for urine pretreatment requires 5 grams per liter of urine to achieve effectivity. An initial down-select study was performed following Table 2 pretreatment parameters to understand which combination of oxidant/bactericide/acid provides effectiveness in reducing turbidity, Dissolved Oxygen (DO), and microbial management at each planned sampling day over the course of 28 days.

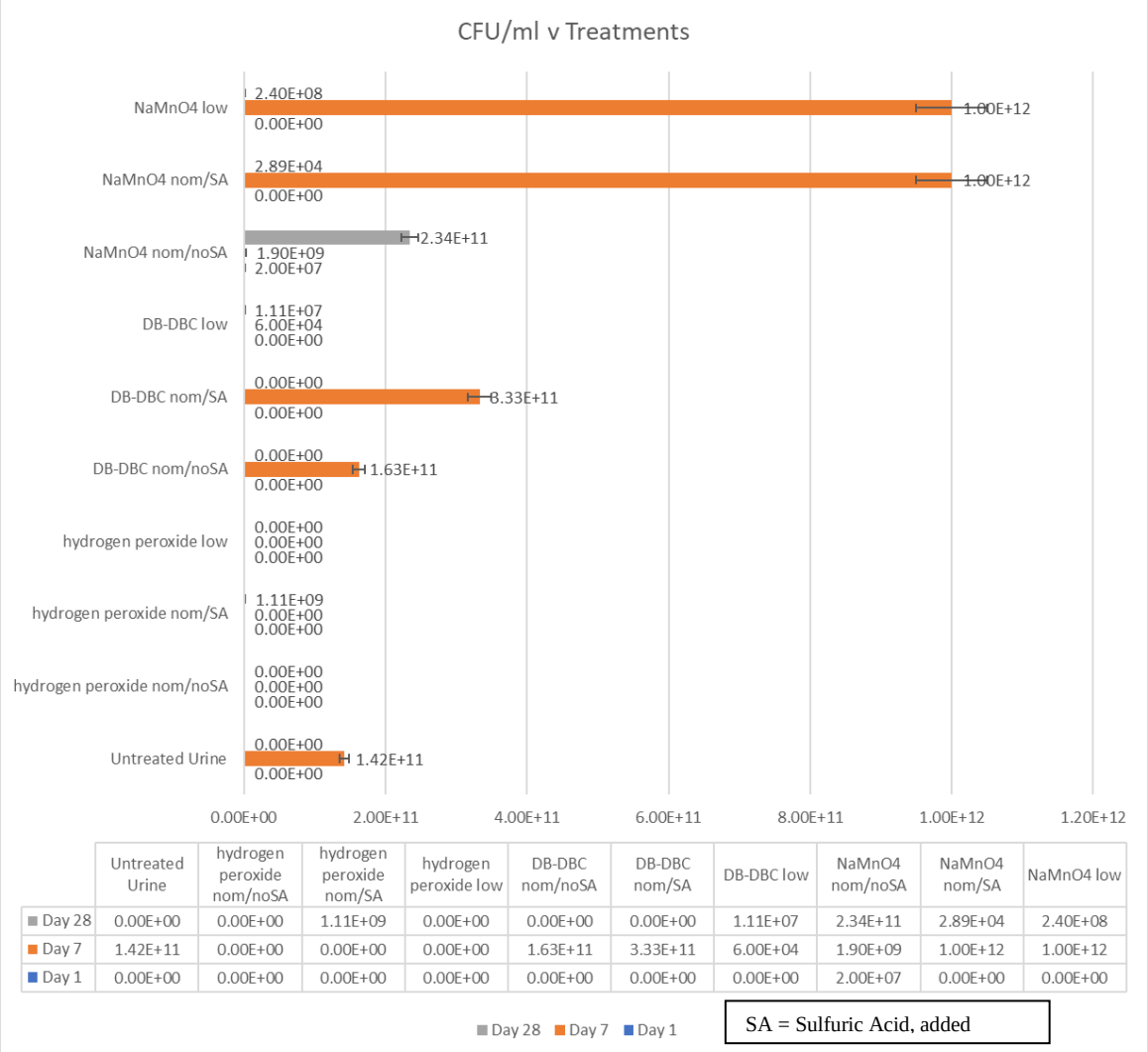
Table 2: Variable Urine Pretreatment Test Parameters for Downselect

Pretreat	Pretreat Concentration	Sulfuric Acid Concentration
Control (*no treatment*)	**N/A**	-
n-Bronopol (*2-Bromo-2-nitro-1,3-propanediol*)	**1 g/L-urine**	Sulfuric Acid (1 mL/g pretreat)
	2 g/L-urine	-
H_2O_2	**1 g/L-urine**	Sulfuric Acid (1 mL/g pretreat)
	1 g/L-urine	-
	0.5 g/L-urine	-
DB-DCB (*1,2 dibromo-2,4-dicyanobutane*)	**1 g/L-urine**	Sulfuric Acid (1 mL/g pretreat)
	1 g/L-urine	-
	0.5 g/L-urine	-
$NaMnO_4$	**1 g/L-urine**	Sulfuric Acid (1 mL/g pretreat)
	1 g/L-urine	-
	0.5 g/L-urine	-

Microbial analysis was performed by collecting urine from sample bottles (2.5 mL) using a bulb pipette. Subsequently, the samples, including the control, were diluted 8 times by adding 10 µl of urine into 90 µl of 0.8% saline water. These were then plated in triplicate using Lennox Broth agar (LB) while using the drop plate method. Samples were then incubated at 25°C for 24 hrs. Later, microscopy of crystals and fungi was performed using 10% crystal violet with urine solution containing crystals and calcofluor white to stain hyphae in the sodium permanganate samples. Figure 2 summarizes the variable pretreatments for microbial activity. Note, Bronopol was not included in this data summary due to early removal ahead of a restart and simplification to accelerate result. In general, the bronopol was not a leading candidate from initial testing indicating elevated turbidity numbers within a 28 day of urine stabilization. The control, 'untreated' raw urine, did show microbial activity providing a viable test sequence to compare to variable pretreatment activities. Perhaps one of the most ineffective urine pretreatments tested in parallel was the potassium permanganate sequences. For both the low (0.5 g/L-urine) and nominal (1.0 g/L-urine) + sulfuric acid, significant CFU counts were reported. These had orders of magnitude higher than most other candidates. The next two closest in elevated CFU counts the DB-DBC nominal (1.0 g/L-urine) + sulfuric acid and nominal (1.0 g/L-urine) with no added sulfuric acid. The overgrowth compared to the control suggests additional nutrient loads became available from the urine or additives break-down, or a contamination event during sampling. The only other significant CFU count reported was for the nominal concentration with no sulfuric acid for the remaining permanganate test

parameter. This test sequence suggests that concentration was ineffective at any microbial control as these results were similar in magnitude to the control.

The remaining test candidates, DB-DBC low dose (0.5 g/L-urine) and all hydrogen peroxide (with/without sulfuric acid) provided significant microbial reduction compared with untreated urine. The remainder results for pH, DO, and turbidity primarily indicated significant deviation of the control for the sodium permanganate. However, the pH on the controlled, untreated urine, did not show significant increase as expected for urea hydrolysis due in large part to the availably of the urease enzyme. Table 3 summarizes the pH results from Day 1 to Day 28. The limited increase in the control, untreated urine, indicates very little urease enzyme present. This could mean that the control had low microbial growth, or conservatively high challenge for pretreatment studies. But this does not take away from the earlier CFU count confirming measurable and significant levels for an effective round of testing. This set of pH data suggests that future testing will need high microbial growth to effectively challenge the down select. Based on the CFU counts in combination with the secondary measurements (pH, turbidity, DO) the down-select to hydrogen peroxide was chosen for more robust urine pretreat studies and for relevant testing during PUP hardware maturation. The peroxide pretreatment was selected for its urine stabilization properties, including slowing urea decomposition, and preventing microbial growth. It was also chosen due to its potential for *in-situ* extraction and production on planetary bodies.



	Untreated Urine	hydrogen peroxide nom/noSA	hydrogen peroxide nom/SA	hydrogen peroxide low	DB-DBC nom/noSA	DB-DBC nom/SA	DB-DBC low	NaMnO4 nom/noSA	NaMnO4 nom/SA	NaMnO4 low
Day 28	0.00E+00	0.00E+00	1.11E+09	0.00E+00	0.00E+00	0.00E+00	1.11E+07	2.34E+11	2.89E+04	2.40E+08
Day 7	1.42E+11	0.00E+00	0.00E+00	0.00E+00	1.63E+11	3.33E+11	6.00E+04	1.90E+09	1.00E+12	1.00E+12
Day 1	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.00E+07	0.00E+00	0.00E+00

Figure 2. Total CFU/mL Results for $NaMnO_4$, DB-DBC, and Hydrogen Peroxide.

Table 3. pH Results for $NaMnO_4$, DB-DBC, and Hydrogen Peroxide.

pH Day 1										
	Sample									
	Control Urine	Nominal DB-DCB	Nominal DB-DCB + H2SO4	Low DB-DCB	Nominal H2O2	Nominal H2O2 + H2SO4	Low H2O2	Nominal NaMnO4	Nominal NaMnO4 + H2SO4	Low NaMnO4
REP 1	5.993	6.061	2.48	6.087	5.918	2.524	5.969	7.396	4.26	6.857
REP 2	5.992	6.107	2.466	6.059	5.923	2.557	5.948	7.402	4.228	6.884
REP 3	5.986	6.103	2.491	6.009	5.96	2.486	5.956	7.425	4.26	6.851
AVG	5.99	6.09	2.48	6.05	5.93	2.52	5.96	7.41	4.25	6.86

pH Day 7										
	Sample									
	Control Urine	Nominal DB-DCB	Nominal DB-DCB + H2SO4	Low DB-DCB	Nominal H2O2	Nominal H2O2 + H2SO4	Low H2O2	Nominal NaMnO4	Nominal NaMnO4 + H2SO4	Low NaMnO4
REP 1	5.98	5.9	2.5	5.9	5.95	2.5	5.97	5.68	4.3	6.7
REP 2	5.96	5.8	2.5	5.9	5.9	2.51	5.93	5.9	4.3	6.65
REP 3	5.95	5.9	2.5	5.9	5.94	2.5	5.95	7	4.3	6.72
AVG	6.0	5.87	2.5	5.9	5.9	2.5	6.0	6.2	4.3	6.69

pH Day 28										
	Sample									
	Control Urine	Nominal DB-DCB	Nominal DB-DCB + H2SO4	Low DB-DCB	Nominal H2O2	Nominal H2O2 + H2SO4	Low H2O2	Nominal NaMnO4	Nominal NaMnO4 + H2SO4	Low NaMnO4
REP 1	5.85	5.78	2.46	5.82	5.95	2.47	5.92	5.95	4.41	6.24
REP 2	5.88	5.79	2.45	5.83	5.97	2.45	5.91	6.06	4.52	6.05
REP 3	5.88	5.81	2.45	5.84	5.99	2.53	5.9	6.09	4.47	6.13
AVG	5.9	5.79	2.5	5.8	6.0	2.5	5.9	6.0	4.5	6.14

2. Hydrogen Peroxide Parametric Testing

As a continuation of our downselect, three different concentrations of hydrogen peroxide were tested: Low (0.5 g/L-urine), Nominal (1.0 g/L-urine), High (1.5 g/L-urine) without sulfuric acid addition. To ensure adequate urease enzyme introduction to the test urine batches, a small batch of urine was allowed to age, monitoring for pH increase. The aged urine was later dosed to each sample set to ensure proper seeding with urease and active, urine-relevant microbes. For this test sequence, this was approximately $1x10^4$ CFU/mL concentration. The test was conducted for 28 days with sampling and analysis on days 0, 7, and 28. To assess efficacy of the treatment, pH was also analyzed. Microbiological methods were the same as the down-select, however, Reasoner's 2A agar (R2A), and Sabourad Dextrose agar (SDA) plates were also used at 25°C. For SDA, samples were allowed to grow for at least 7 days. After the testing sequences, the test articles were allowed to store for an additional 173 days for another round of samples were seeded again with $2x10^{12}$ CFU/mL and allowed to incubate for at least five (5) days and analyzed for pH changes and growth on solid media thereafter. The intent of this 're-seeding' was to understand the residual effects and how resistive the hydrogen peroxide and pH effect would be.

Overall, the results showed that all concentrations effectively inhibited growth and only the control, untreated urine samples yielded microbial growth higher than 10^7 CFU/mL. No fungal growth was found in SDA or other media. Moreover, samples from this test series continued to resist growth for as long as 6 months following the original hydrogen peroxide addition, even with the addition of aged urine (source of elevated CFU counts). This is an important data point as it indicates a viable path to understand how stored, or rather, residual pretreated urine in nominal operations and dead volumes within a given system and how potential disruptions or introduction of excessive microbial burden may be mitigated.

This parametric test did conclude that all three concentrations of hydrogen peroxide testing were viable at controlling microbial growth; however, there were still notable levels of the low (0.5 g/L-urine) peroxide testing in the down-select testing. To that end, at minimum it is recommended to use a 1 g/L-urine peroxide to stabilize urine. Similar testing of graywater stabilization using hydrogen peroxide for exploration of partial gravity water recovery studies concluded the use of a 1.5 g/L-graywater versus 1 g/L-graywater to provide viable microbial stabilization[3]. As such, PUP testing will use the more conservative 1.5 g/L-urine hydrogen peroxide stabilized urine. Further testing will explore more robust urine stabilization assessments and reconsideration of 1 g/L-urine will be pursued.

B. Evaporator and Precipitate Bag Development

The initial proof of concept PUP evaporator was developed using an 8" diameter stainless steel tube with a welded bottom and a removable polycarbonate lid to allow for process inspection (Figure 3). The feed and product fluid interfaces were routed through the evaporator lid, with additional vacuum ports on the side of the evaporator to balance pressures on either side of the bag. External flexible adhesive heaters were placed on the evaporator to provide the heat needed to drive the distillation process. The selected heaters have a low power density of 2.5 to 5 Watts/in^2 to minimize ammonia evolution during the distillation process.

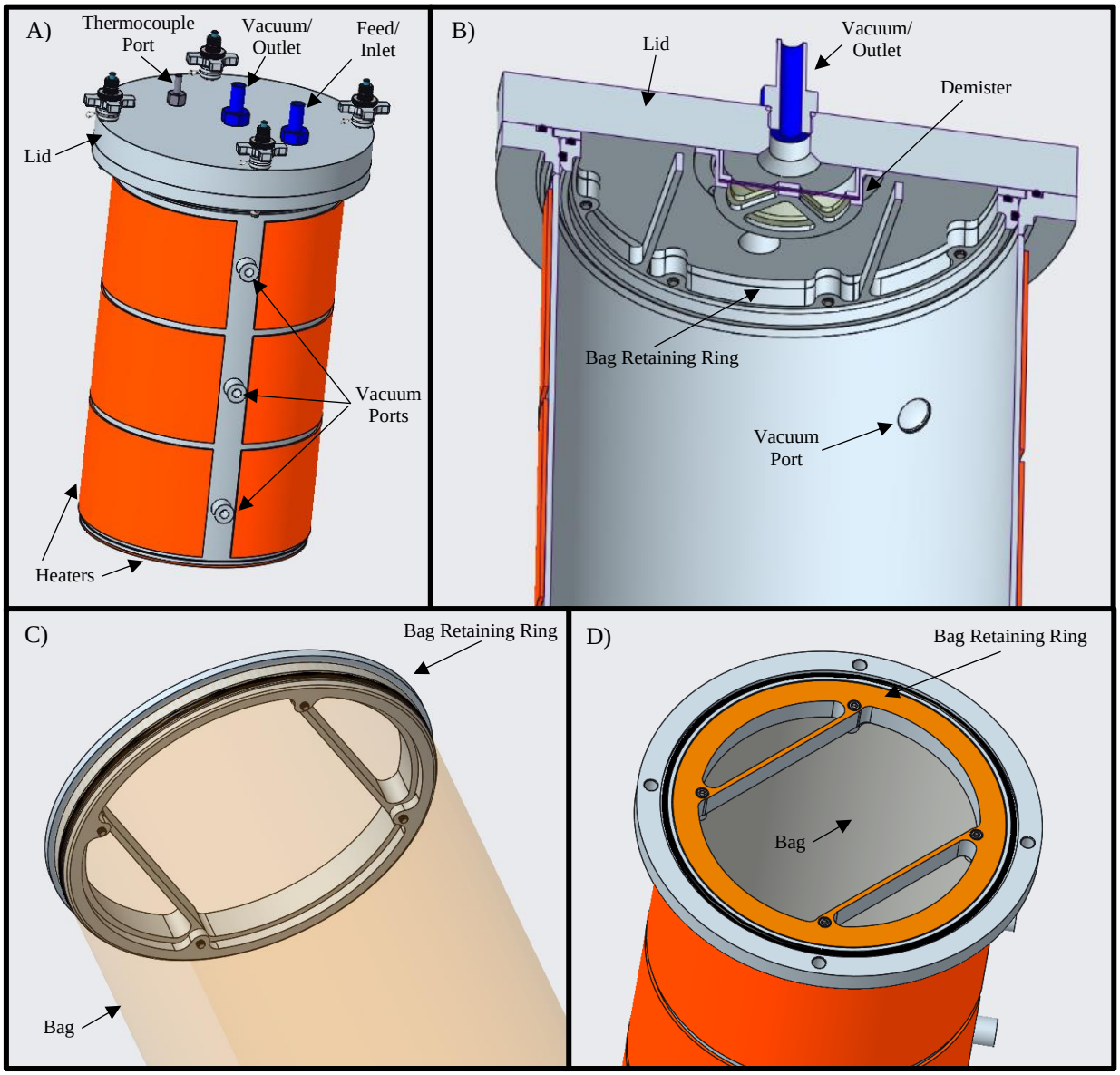


Figure 3. A) Model of evaporator. B) Model of inside of evaporator. C) Model of bag ring with bag installed. D) Model of evaporator with bag & ring installed.

The initial hardware design tested had an open top bag which enabled direct measurement of the liquid temperature inside the evaporator, while testing the bag's capability to contain the liquid and withstand the thermal and structural loads experiencd during use. This configuration was first tested with water, then salt water, and finally with H_2O_2-pretreated urine. Figure 4 shows the inside of the evaporator at the end of a salt water process run. With successful test results of up to 99% water recovery from H_2O_2-pretreated urine in this configuration, design updates were made for the next test configuration.

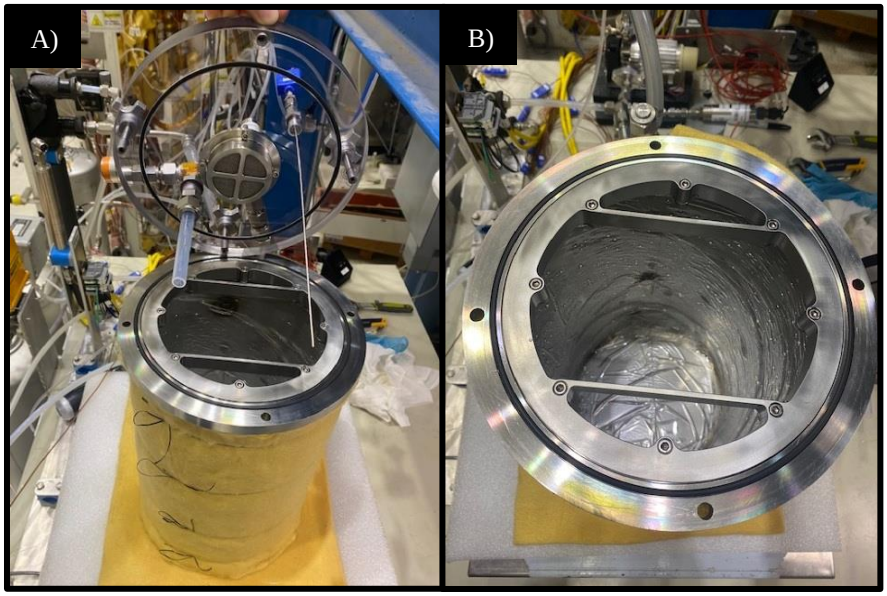


Figure 4. A) Evaporator with open lid showing urine feed port, demister, thermocouple, and nylon bag installed. B) Inside of evaporator with nylon bag installed.

With baseline process parameters and data collected, the next objective was to integrate and test a sealed bag design. Updates were made to the evaporator lid in order to integrate and test different PBs. The initial PB tested was the same 1 mil nylon bag used in the previous configuration. The PB had two holes punched in it for bulkhead fittings utilized as the inlet and outlet ports. Once the bulkhead fittings were installed with PTFE washers, the PB was then heat sealed at the top and installed on the evaporator lid (Figure 5A). The lid was then installed on the evapoarator, and ready for processing. This PB and test configuration successfully processed H_2O_2-pretreated urine up to >97%. After running several tests with this bag, different bag options were pursued due to the difficulty of sealing, and the prevalence of pinhole leaks. Currently, testing is being done with 3 mil polyethylene and nylon multi-layer bags which are providing similar processing results and are leak-free. More testing is planned on several different bags to determine the best suited material(s) and thickness.

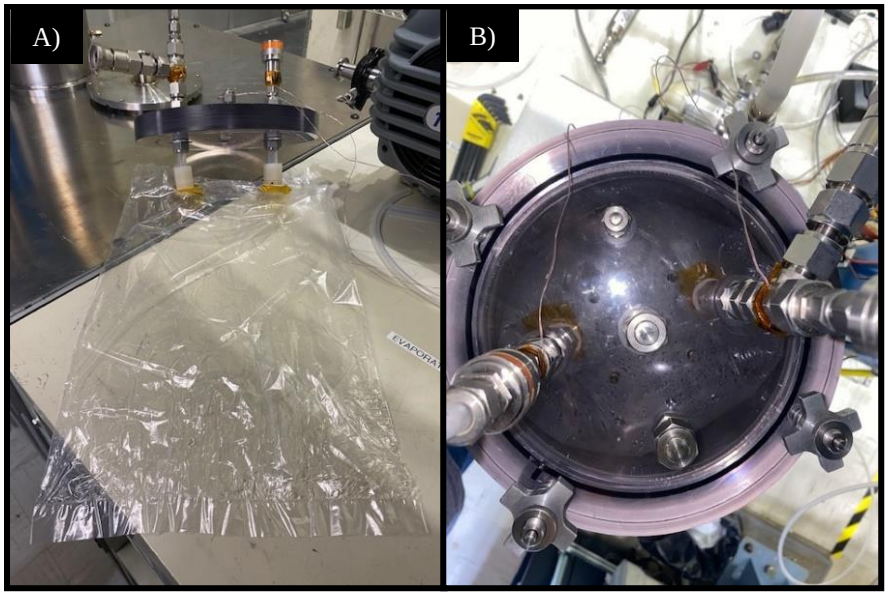


Figure 5. A) Nylon Sealed PB installed on evaporator lid B) Nylon PB inside of evaporator during process run

C. Vacuum Pump Testing

A critical component in the PUP design utilizes a vacuum pump to evacuate the evaporating chamber of generated water vapor and non-condensable gases. This volume being evacuated is saturated with water vapor and condensing this water vapor will occur given appropriate pressure and temperature changes. As such, there are limited vacuum

pumps that can handle this wetted environment while maintaining adequate pumping efficiencies. Advanced pump technologies have improved since the development of the ISS's UPA, the baseline technology for PUP. The UPA utilizes peristaltic pump technology to provide the necessary vacuum condition in the distillation assembly. Recent development efforts have produced a scroll pump technology to replace the existing peristaltic purge pump on ISS. This technology demonstration flight project is targeted to be installed in the UPA in the spring of 2023. This development led the PUP project to explore similar scroll pump technology as a solution to provide the necessary vacuum conditions in the evaporator. Early testing has been limited to a commercial off the shelf (COTS) equivalent to the UPA's scroll pump. Though the UPA's flight version of the scroll pump is optimized to withstand liquid and air media and has been tested on the ground to have a life of >3000 hours, the COTS scroll pump is intended to pump gas and is therefore susceptible to internal corrosion. Because of this, the COTS pumps tested were only able to operate for limited number of hours (typically <300) until pump failure due to internal corrosion. Despite the corrosion concerns, the scroll pump technology has shown viability in the PUP design due to its ability to continuously pump a liquid/air mixture, its low power consumption, and its low volume and mass. The project has recently procured an upgraded scroll pump similar to the UPA's scroll pump to further analyze the viability of scroll pump technology in this system.

IV. Process Run Results

A test of two consecutive urine process runs was conducted over two days using the same PB to demonstrate the PUP system and to collect preliminary data. These test runs processed urine collected on-site and treated with hydrogen peroxide at a rate of 1.5 g/L-urine. Figure 6 and Figure 7 show production rates and cumulative distillate of these runs. As PUP starts up, the pretreated urine is heated to ~38 °C and a vacuum pulled to ~40 mmHg, and the production rate increases to around 0.9 lb/hr within the first two hours. Between hours 3-9, the process rates increase up to a maximum of 1.3 lb/hr. After hour 11, the process rates rapidly decrease as the water recovery rates exceed 95%. The process runs last nominally 16 hours to get to >96% water recovery (Figure 8). The raw data for this test is shown in Table 4.

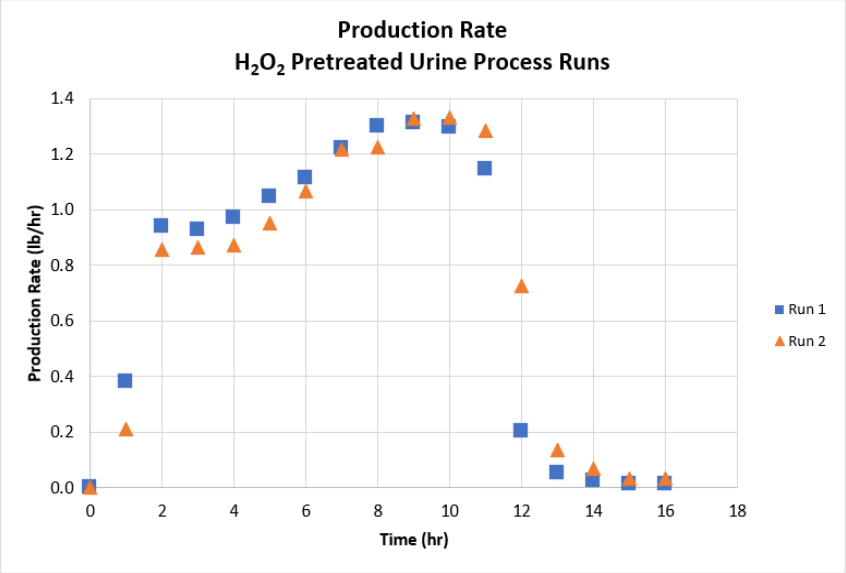


Figure 6. Production rate during two consecutive urine + H_2O_2 process runs with the same PB.

Table 4. Data from day 1 & 2 process runs.

Process Run Data															
Run 1 (started with 12.3 lb urine + H_2O_2)								Run 2 (started with 12.7 lb urine + H_2O_2)							
Time (hrs)	Product Water Conductivity (µS/cm)	Product Water (lb)	Production Rate (lb/hr)	Percent Water Recovery (%)	Evaporator Pressure (mmHg)	Temp. (C)	Energy (kWh)	Time (hrs)	Product Water Conductivity (µS/cm)	Product Water (lb)	Production Rate (lb/hr)	Percent Water Recovery (%)	Evaporator Pressure (mmHg)	Temp. (C)	Energy (kWh)
0.0	41.9	0.0	0.00	0.0	225.6	37.9	0.000	0.0	1800.9	0.0	0.00	0.0	250*	23.4	0.000
1.0	200.6	0.4	0.38	3.1	43.5	50.8	0.243	1.0	745.3	0.2	0.21	1.7	47.0	48.2	0.297
2.0	118.6	1.3	0.94	10.8	43.4	51.4	0.535	2.0	134.1	1.1	0.86	8.4	45.4	51.4	0.613
3.0	109.4	2.3	0.93	18.3	44.0	50.4	0.820	3.0	122.9	1.9	0.86	15.2	45.5	51.4	0.928
4.0	108.9	3.2	0.97	26.2	44.2	50.1	1.117	4.0	126.8	2.8	0.87	22.1	45.7	51.6	1.254
5.0	108.4	4.3	1.05	34.8	44.4	48.0	1.436	5.0	128.7	3.8	0.95	29.6	46.4	49.4	1.602
6.0	109.8	5.4	1.11	43.8	44.4	51.3	1.790	6.0	126.7	4.8	1.07	38.0	47.6	51.2	1.969
7.0	112.2	6.6	1.22	53.8	45.8	51.5	2.187	7.0	127.9	6.0	1.22	47.6	46.7	50.1	2.374
8.0	121.1	7.9	1.30	64.3	45.9	50.5	2.593	8.0	137.3	7.3	1.23	57.3	47.0	48.7	2.799
9.0	127.2	9.2	1.31	75.0	45.7	49.3	3.025	9.0	153.6	8.6	1.33	67.7	46.4	47.8	3.225
10.0	164.1	10.5	1.30	85.5	45.5	48.7	3.456	10.0	185.1	9.9	1.33	78.2	46.8	46.9	3.647
11.0	728.6	11.7	1.15	94.9	39.7	48.5	3.873	11.0	257.4	11.2	1.29	88.3	46.6	49.5	4.030
12.0	1165.4	11.9	0.20	96.5	39.6	51.7	4.117	12.0	751.9	11.9	0.73	94.1	43.4	49.1	4.099
13.0	1437.2	11.9	0.05	96.9	39.7	50.6	4.169	13.0	1122.9	12.1	0.14	95.1	43.3	51.8	4.122
14.0	1573.7	11.9	0.02	97.1	33.4	50.5	4.199	14.0	1322.6	12.2	0.07	95.7	41.8	49.5	4.140
15.0	1701.3	12.0	0.01	97.3	29.0	49.0	4.223	15.0	1314.6	12.2	0.03	95.9	41.7	48.6	4.156
16.0	1812.6	12.0	0.01	97.4	27.8	48.5	4.247	16.0	1327.9	12.2	0.03	96.2	37.1	51.6	4.172

*250 mmHg is the upper limit of the pressure transducer used, therefore this value can be assumed to be greater.

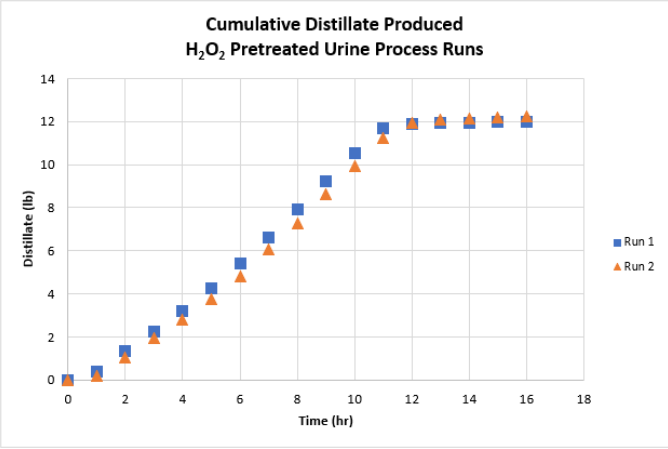


Figure 7. Cumulative distillate during two consecutive urine + H_2O_2 process runs with the same PB.

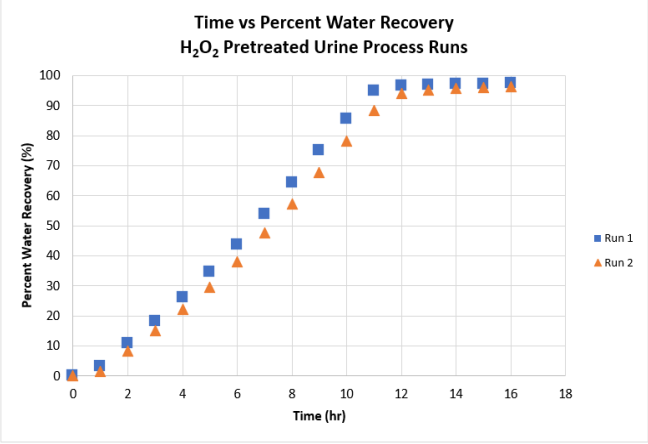


Figure 8. Time required to reach a given recovery rate starting with avg. 12.5 lb urine + H_2O_2.

Proof of concept testing of the PUP has consistently demonstrated a >96% water recovery rate, with a maximum rate of 99% achieved, compared to the 87% rate of the current ISS UPA. A more detailed trade study is planned to analyze the cost of increasing the recovery rate from 96% to 99%. Similar to the UPA on ISS, the PUP utilizes a process monitoring system to accept or reject distillate while processing (Figure 1). When the distillate is below a defined conductivity maximum value, it is accepted and routed to the product tank. When the distillate exceeds the defined conductivity maximum value, it is rejected and sent back into the pretreat tank to be reprocessed during the next run. Initially, the PUP control program was set to reject distillate exceeding 500 microsiemens per centimeter (µS/cm). For reference, the ISS Urine Processor has a reject value at 400 microsiemens per centimeter; however that system processes urine, currently to 87% recovery. During testing, it was observed that distillate conductivity would not exceed this limit until >93% water recovery. Due to the small amount of remaining water

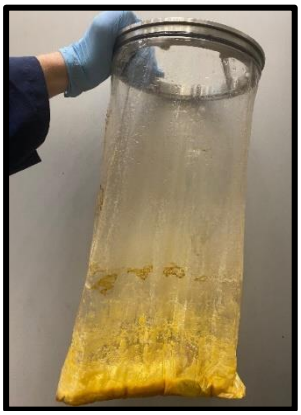


Figure 9. Brine/foam left after 99% water recovery.

(~3%) required to complete a process run, the PUP control program was updated to accept all distillate, regardless of conductivity. Samples of the distillate tank were taken at the end of process runs to gather data on distillate quality. Distillate testing included pH, TOC, conductivity, and anion testing (Table 5). Note that the distillate is not considered potable and needs further 'polishing' similar to the UPA distillate that is sent to the Water Processor Assembly (WPA) for further processing. PUP distillate test results indicate that PUP distillate quality is consistent with UPA distillate. Notably, there are slight differences in the conductivity and TOC between PUP and UPA distillate, presumably due to the lack of acid in the PUP urine pretreatment.

Table 5. PUP distillate tank sample analysis after day 1 & 2 process runs.

Sample	pH	Conductivity (µS/cm)	TOC (ppm)	Ammonium (ppm)	Calcium (ppm)	Lithium (ppm)	Magnesium (ppm)	Potassium (ppm)	Sodium (ppm)
Day 1	8.87	198	8.09	59.63	<0.30	ND	<0.3	<0.30	7.25
Day 2	8.61	240	9.46	57.50	<0.30	ND	2.13	0.60	0.40

ND – not detected at the dilution required

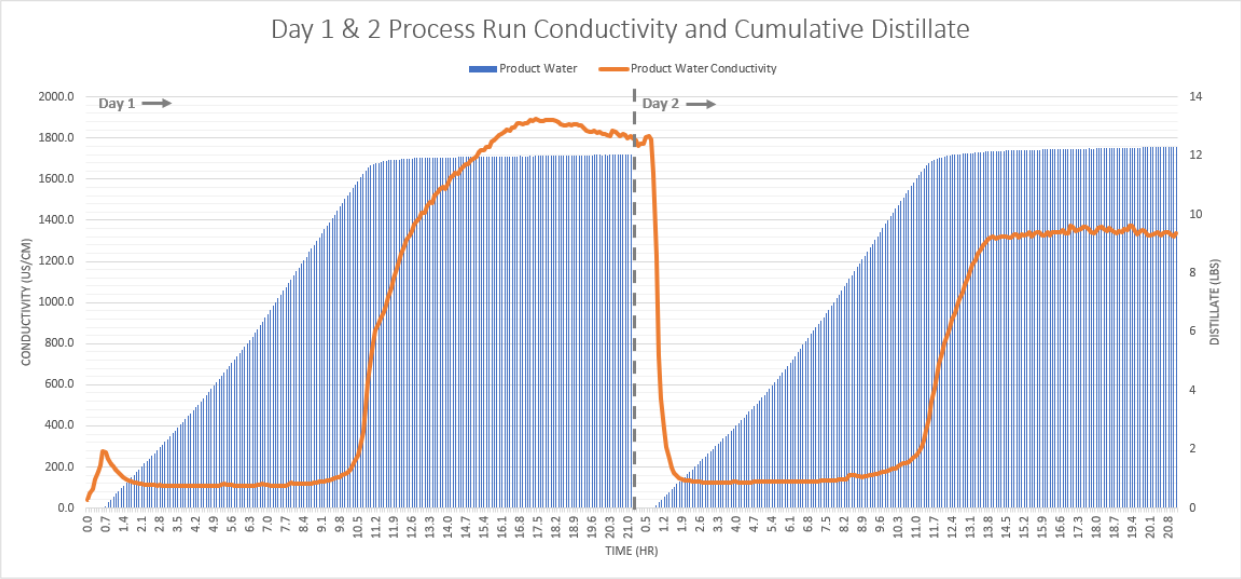


Figure 10. Conductivity & cumulative distillate during 2-day urine + H_2O_2 test with same PB.

V. Future Work

Future work will focus on bag integration design updates, process improvements, and long term (life) testing of the system. Additional concepts of PUP will be pursued to further push heat loss and potential improved efficiencies. These designs will take advantage of either latent heat recovery and dedicated heating chambers with more efficient heater operations to reclaim remaining water. Further urine stabiliation studies will continue to understand more long term operations and recosideratin of a lower hydrogen peroxide concentrations.

VI. Conclusions

The PUP explores the applicability of a simplified vacuum distillation process for planetary applications. The initial concept utilizes a disposable liner that will accumulate urine brine over time. After reaching its maximum capacity of brine, this liner will be replaced with a new liner for continued urine processing. This single step urine processing technology achieves >96% water recovery and avoids the need for a secondary recovery step, such as a brine processor. This initial concept design is showing promising results that reach >96% recovery. There are still

areas of improvements, be it liner design and exploring further power saving designs. Finally, the use of a greener urine stabilizer was also explored to improve upon the current stabilizers in use. Of the four (4) options explored, hydrogen peroxide, was the leading candidate. Further testing will continue to confirm this viable option, challenging with more conservative, worst-case scenarios.

Acknowledgments

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