ICES303-D: AIChE/IIC – Physio-Chemical Life Support – Water Recovery & Management Systems – Technology and Process Development

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

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Planetary Urine Processor (PUP)

- The goal of this activity is to develop a partial gravity urine processor to utilize the partial gravity available on the Moon ($\frac{1}{6}g$) or Mars ($\frac{1}{3}g$).
- Design requirements and goals are derived from the ECLSS BVAD, NASA-STD-3001 and CONOPS defined under the Artemis Base Camp.
- The Planetary Urine Processor (PUP) concept must include provisions to capture and store any waste products produced through the urine reclamation.
- Final disposition of the waste is *TBD* per Planetary Protection Protocols.

Design Loads/Requirements

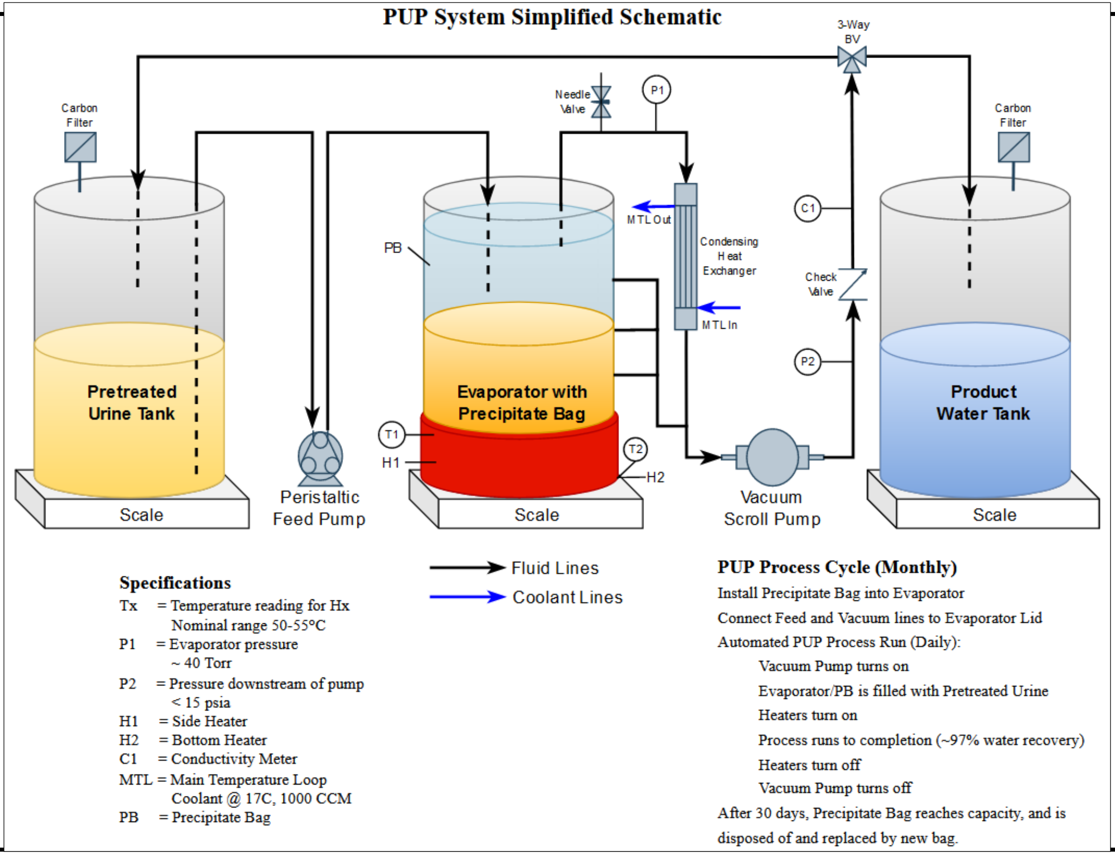
	Units	Value
Urine	lb/CM-day	3.31
Flush	lb/CM-day	1.09
Recovery Efficiency	%	>95
Total Dissolved Solids	mg/L	43300
Urea	mg/L	23300
Pretreat Formulation	mL/Flush	3.30
# of Crew	-	4
Duty Cycle	%	>60
Operating Temperature	^oF	~100

- Penalties for up/down mass to/from lunar or planetary habitats may necessitate high water recovery rates from urine waste feeds.
- Nearly 100% recovery may be desirable for lunar or planetary surface habitats. Any water adds volume and mass.
  - Unable to discard separated urine solids and pretreatment on the lunar or planetary surfaces so must be returned
- Anticipate an increased duty cycle versus ISS UPA to achieve lower processing rate and ostensibly lower size.
  - A 66% duty cycle (16 hours out of 24 hours) results in 1.1 lb/hr rate, approximately 33% of current capacity.
- Daily dormant period (6-8 hours per day) may be used to precondition or collect urine for the next operational cycle.
- Operation at a higher temperature may have some power/size advantages but could be offset by ammonia generation and increased insulation.

UPA Comparison

	Units	UPA	PUP-1
Processing Rate	(lbs/hr)	3.5	1.1
Evaporator Pressure	(mmHg)	36.0	30-40
Evaporator Area	(in^2)	490.0	200.0
Evaporator Volume	(liter)	24.4	10.0
Gravity	(g)	~9g (induced)	$\frac{1}{6}, \frac{1}{3}, 1g$

Concept 1 Overview



- Concept is to gravity or pump feed collected/stabilized urine through a small evaporator to distill clean water.
- Gravity is also utilized for phase separation of non-condensable gases and a small amount of vapor from the product water.
- As the volume of liquid in the evaporator is processed, heavier precipitated solids and non-volatile pretreat solution would displace dilute urine.
- The precipitate bag inside the evaporator would eventually be discarded when full of solids/pretreat solution.

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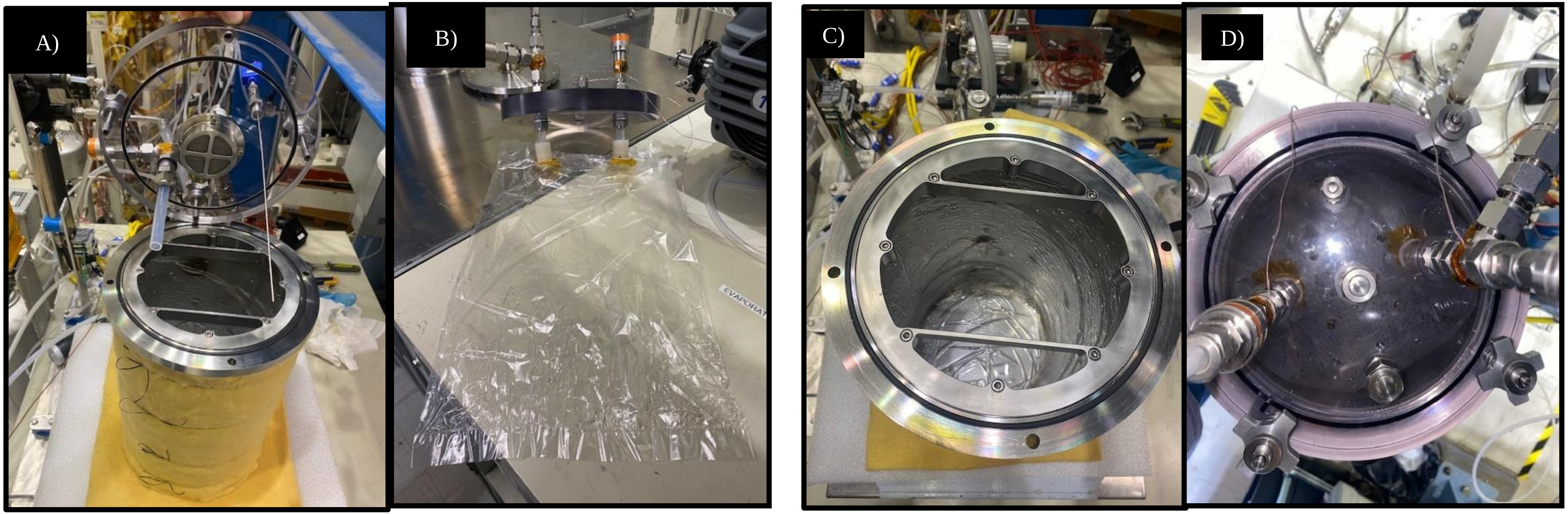

A) Evaporator with open lid showing urine feed port, demister, thermocouple, and nylon bag installed.

B) Nylon Sealed Precipitants Bag installed on evaporator lid

C) Inside of evaporator with nylon bag installed.

D) Nylon Precipitants Bag inside of evaporator during process run

Alternative Pretreat Study

[GOAL]: Find a more 'green' pretreatment that is effective toward microbial control with minimal mass/volume requirements

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)
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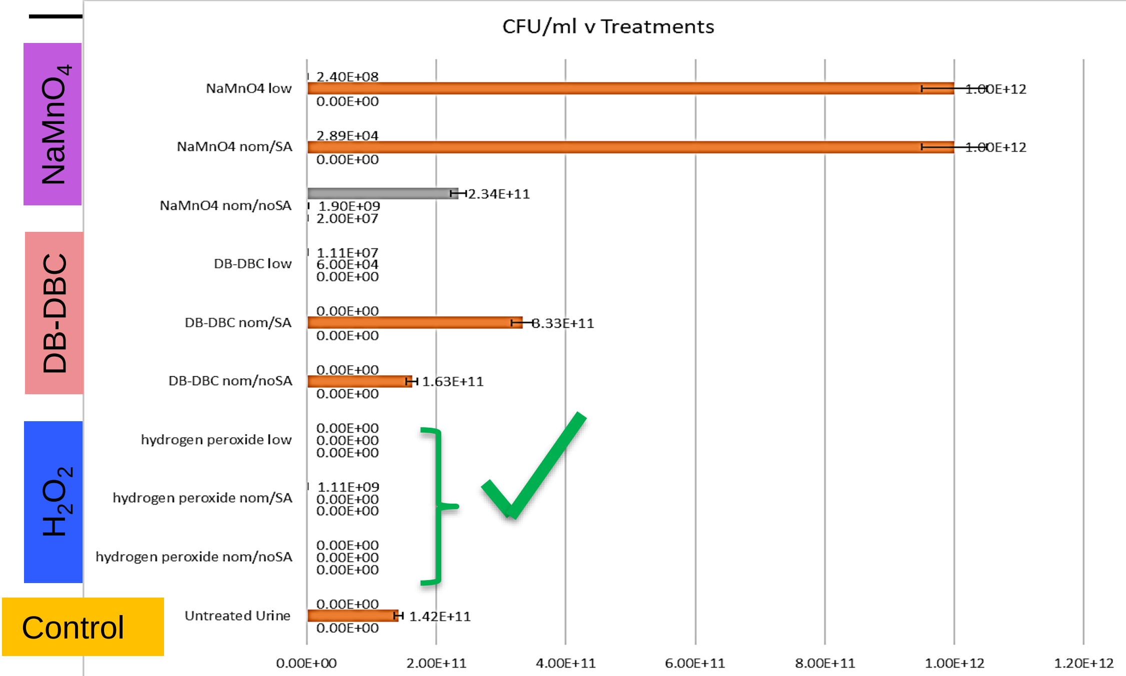
n-Bronopol was removed early off the downselect due to poor urine quality control (turbidity) during initial testing

Pretreat Study Microbial Results



	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

SA = Sulfuric Acid, added

Day 28 Day 7 Day 1

- 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 testing.
- The peroxide pretreatment was selected for its urine stabilization properties, including slowing urea decomposition, and preventing microbial growth.
- It was also chosen due to it's potential for in-situ extraction and production on planetary bodies.

H_2O_2 Parametric Testing

- Subsequent testing with H_2O_2 inoculated ~1x10^4 CFU/mL (via aged urine).
    - Provided urine relevant microbes
    - Increased levels of urease enzyme for better challenges to the peroxide
- Three different concentrations of peroxide were tested:
    - Low (**0.5** g/L-urine), Nominal (**1.0** g/L-urine), High (1**.5** g/L-urine).
    - No sulfuric acid additions were challenged
- Assessed at Day 0, 7, and 28 days
    - Microbial
    - pH

Results:

- Control saw CFU counts increase from 10^4 to >10^7
- All Low, Nominal, High show sufficient microbial control
    - Low (0.5 g/L-urine) did have higher on average observed in earlier down select
- Other independent studies* with peroxide conclude at 1.5 g/L-graywater was necessary for microbial control

*Pinel, I., Hinrichs, J., Castin, A., "*Treatment processes for Partial Gravity Water Recovery Systems*," Technical Report Oct. 2021- Sept. 2022 Company: Lenntech Water Treatment Solutions

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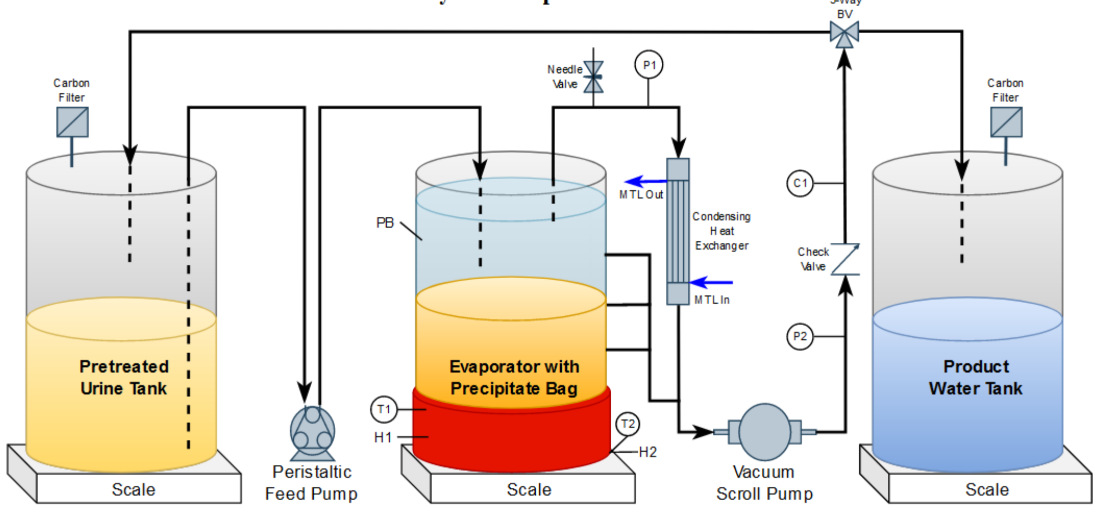
Concept 1 Overview

PUP System Simplified Schematic



Specifications

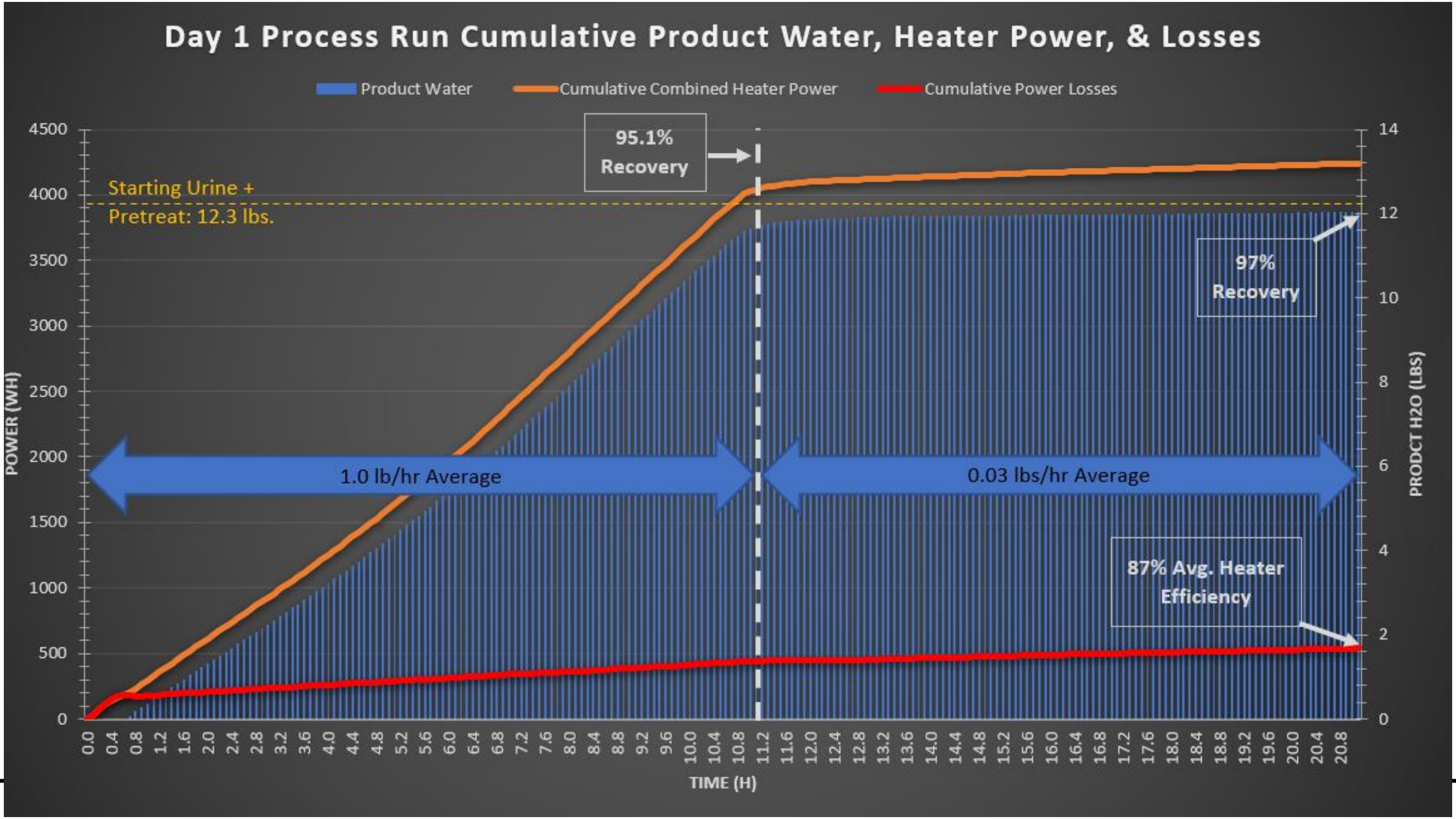
Tx = Temperature reading for Hx
Nominal range 50-55°C
P1 = Evaporator pressure
~ 40 Torr
P2 = Pressure downstream of pump
< 15 psia
H1 = Side Heater
H2 = Bottom Heater
C1 = Conductivity Meter
MTL = Main Temperature Loop
Coolant @ 17C, 1000 CCM
PB = Precipitate Bag

PUP Process Cycle (Monthly)

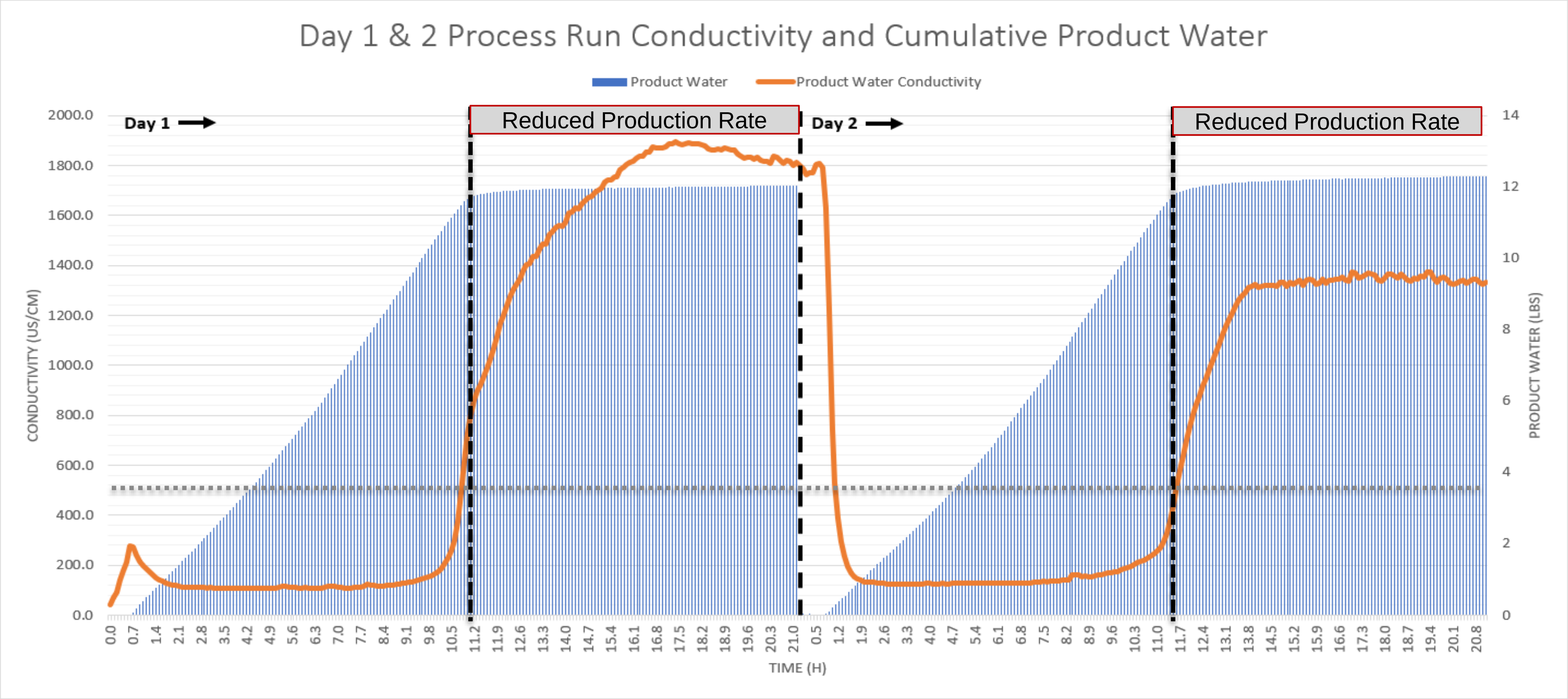
Install Precipitate Bag into Evaporator
Connect Feed and Vacuum lines to Evaporator Lid
Automated PUP Process Run (Daily):
- Vacuum Pump turns on
- Evaporator/PB is filled with Pretreated Urine
- Heaters turn on
- Process runs to completion (~97% water recovery)
- Heaters turn off
- Vacuum Pump turns off

After 30 days, Precipitate Bag reaches capacity, and is disposed of and replaced by new bag.

Concept 1 Process Run Data



Concept 1 Conductivity Data



Conductivity & cumulative product water mass during 2-day urine + H_2O_2 test with same PB.

PUP Concept 1 Products

Remaining solids/brine:

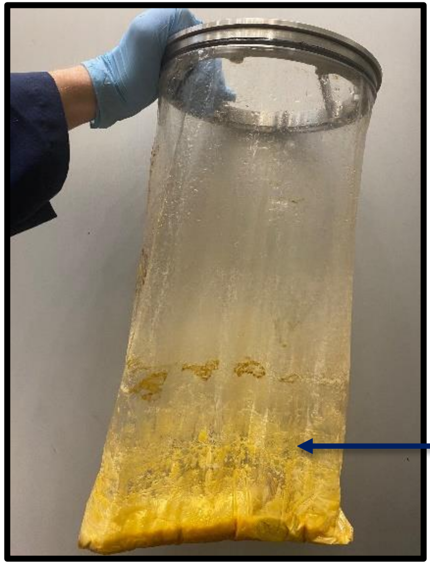


Figure 10. Brine/foam left after 99% water recovery.

~0.5 lbs remaining solids/brine
from ~11 lbs starting urine volume

Collected Product Water, “distillate”:

Total water collected mixed and sampled for full representative analysis
Expected water quality results with unacidified stabilized urine

Table 5. PUP product water 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

Conclusions

- Proof of concept testing of the PUP has consistently demonstrated a >96% water recovery rate, with a maximum rate of 99% achieved
- Preliminary test results seem to indicate that increasing the recovery rate from 96% up to 99% may not be worth the increased time and power required for the minimal volume of product water gained.
- Use of a liner bag shows promise particularly in a reusable application
  - Teams are investigating this durably and system performance with continued Precipitation Bag use
- Experiencing initial foaming of urine after activation
  - Teams are looking to address foaming concerns *(system operations, screens, and/or defoamer)*

Future Plans

- Teams are looking towards alternate Concept 1 designs to improve thermal efficiencies and enhanced production
- These designs will take advantage of either latent heat recovery and dedicated heating chambers with more efficient heater operations to reclaim remaining water
- Revisit the Hydrogen Peroxide with reconsideration of acid modification to further improve product water quality

PUP Team!

- Special thanks to the PUP team for making this project come to life!

Colton Caviglia
Yo-Ann Velez Justiniano
Chelsea McCool
Chelsi Cassily
Greg Schunk
John Thomas
Eric Beitle
Jeff Hansen

Questions?

Thank you for your time!