Results of the FY15 Brine Evaporation Bag (BEB) Technology Down-Select Testing

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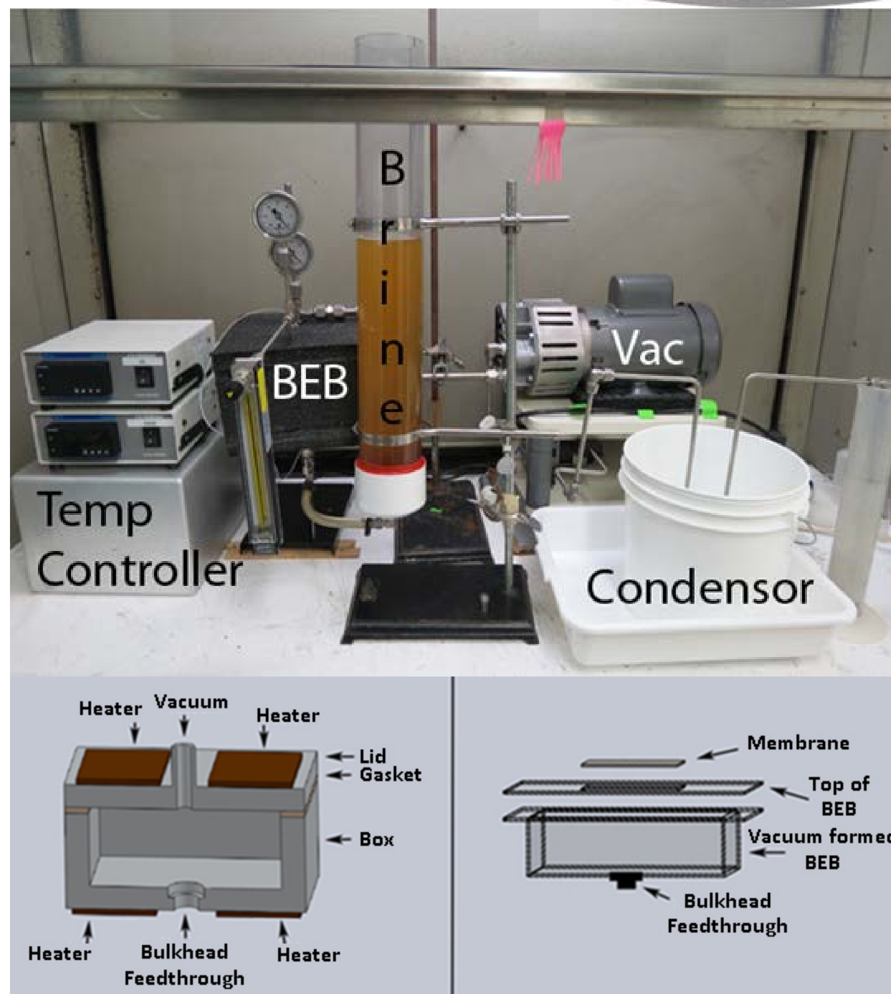
Outline

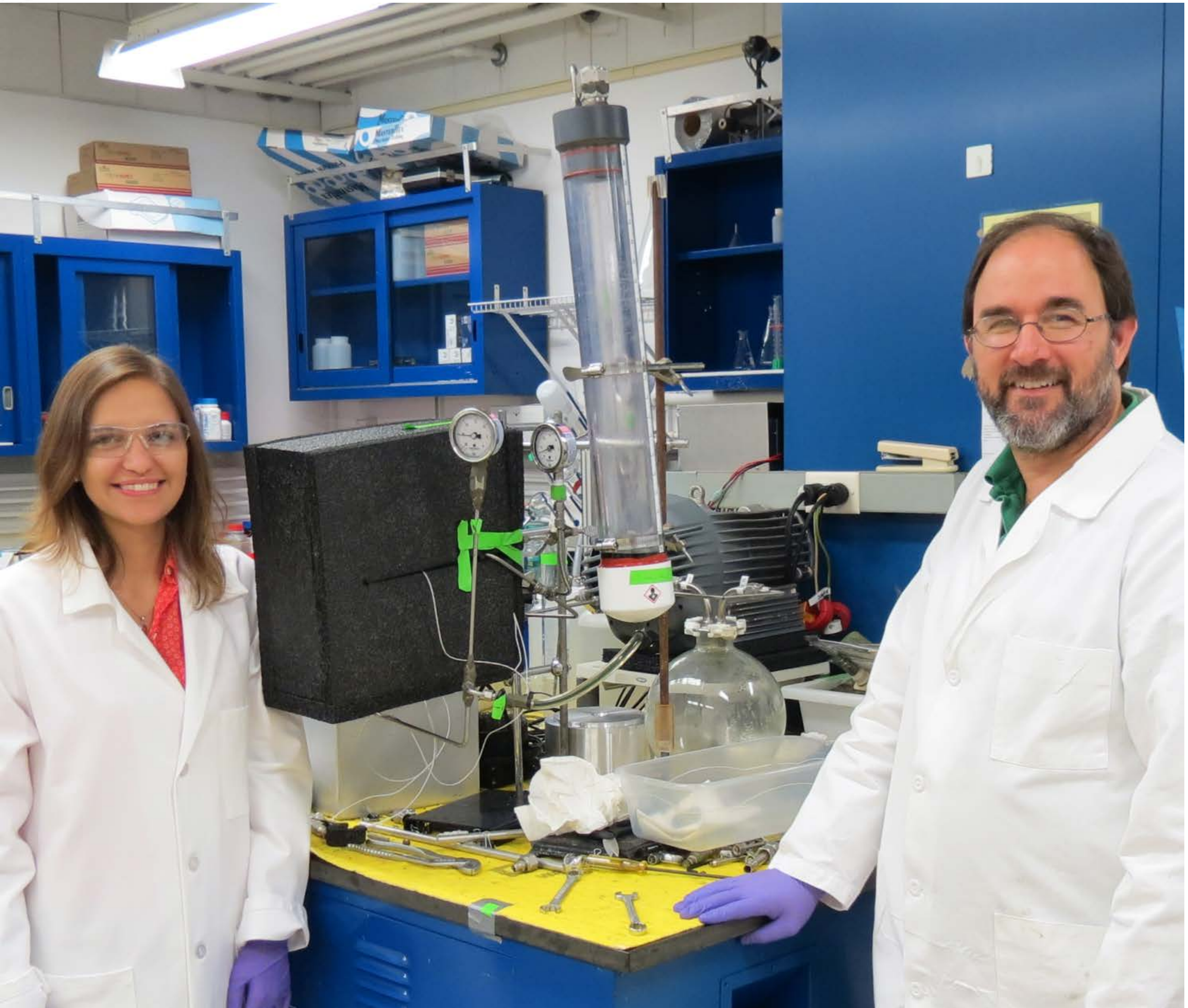
- General description
- Pump comparison
- Description of systems tested
- Temperature effects
- Continuous-fill vs batch mode
- Solidification
- GCMS analysis
- ESM analysis

General Description

- The Brine Evaporation Bag (BEB) System is a brine dewatering system.
- It is composed of the BEB and the BEB Evaporator.
- The BEB contains the brine and keeps it contained during the entire process.
- The BEB has a membrane installed within its sidewall which allows for the water to be removed by the vapor phase keeping the liquids and solids contained within the BEB.
- The BEB Evaporator is the “box” which provides the structural support for the BEB and provides the vacuum and heating required to effect low temperature boiling of the brine within the BEB.

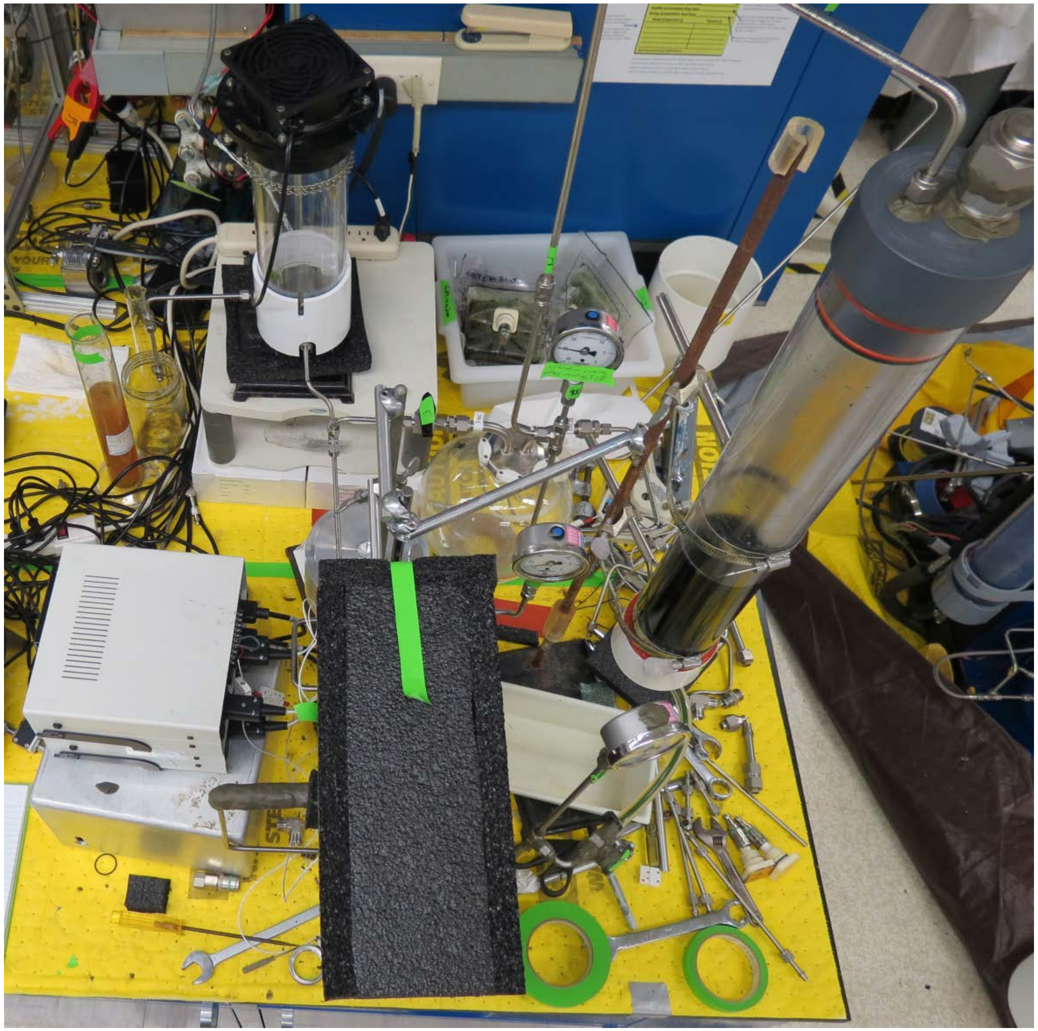


General Description



- Down Select Testing Setup
- Showing:
  - Gen3 Evap.
  - Scroll pump
  - Feed Tank
  - Pressure Control

Scroll Pump Selection

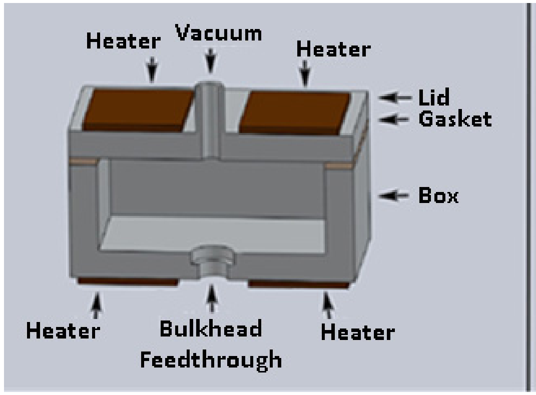


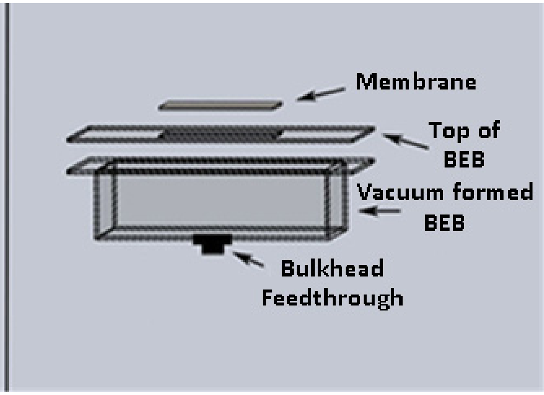
- Air Squared V16
  - 10kg/200W
  - Low reliability
- Edwards
  - 27kg/350W
  - High reliability
- Air Squared V10
  - 2kg/100W
  - Designed for air
- No vacuum pump
  - Connect directly to the UPA

Three BEB Generations Tested

- Gen1 – The initial brass board design
  - Round Feedthrough
  - 5 watt/in^2 heaters
- Gen2 – Shallower profile to investigated diffusional effects
  - Introduced the square Feedthrough
  - 2 watt/in^2 heaters
- Gen3 – Scaleup of Gen1 to determine sizing of ISS prototype
  - Square Feedthrough
  - 5 watt/in^2 heaters

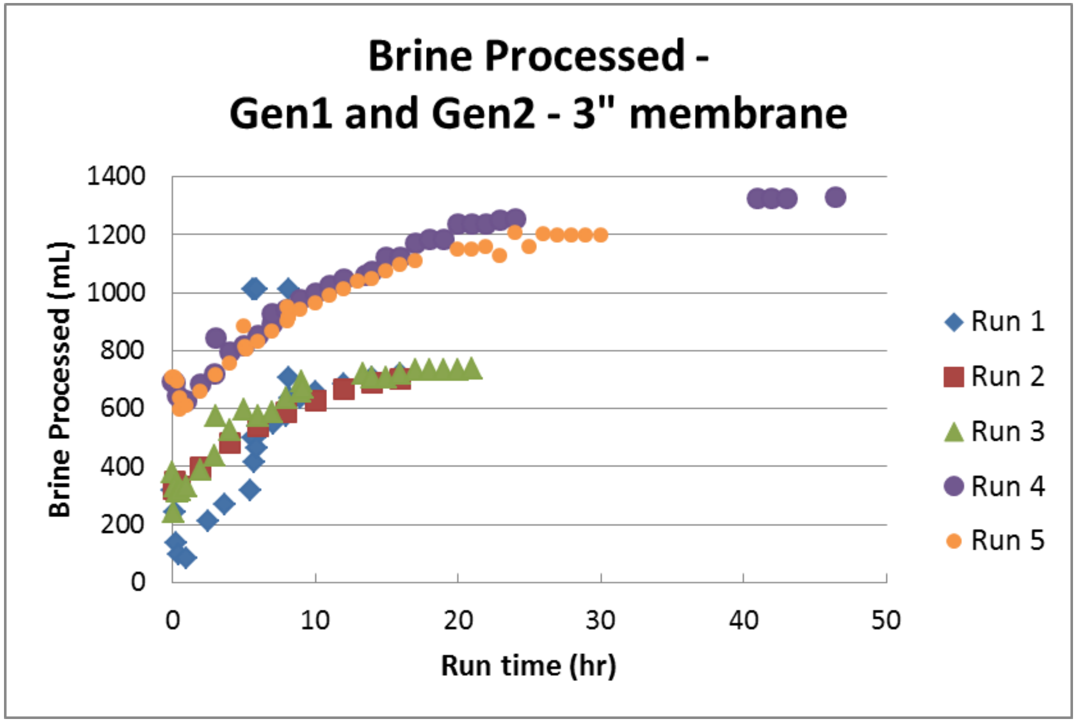
	Evaporator	Bag	Nominal Bag
Gen	Dimensions	Dimensions	Volume
	(inch)	(inch)	(L)
1	6 x 6 x 2.5	4.75 x 4.75 x 2	0.75
2	6 x 6 x 1.5	4.75 x 4.75 x1	0.375
3	11 x 11 x 2.5	9.75 x 9.75 x 2	3





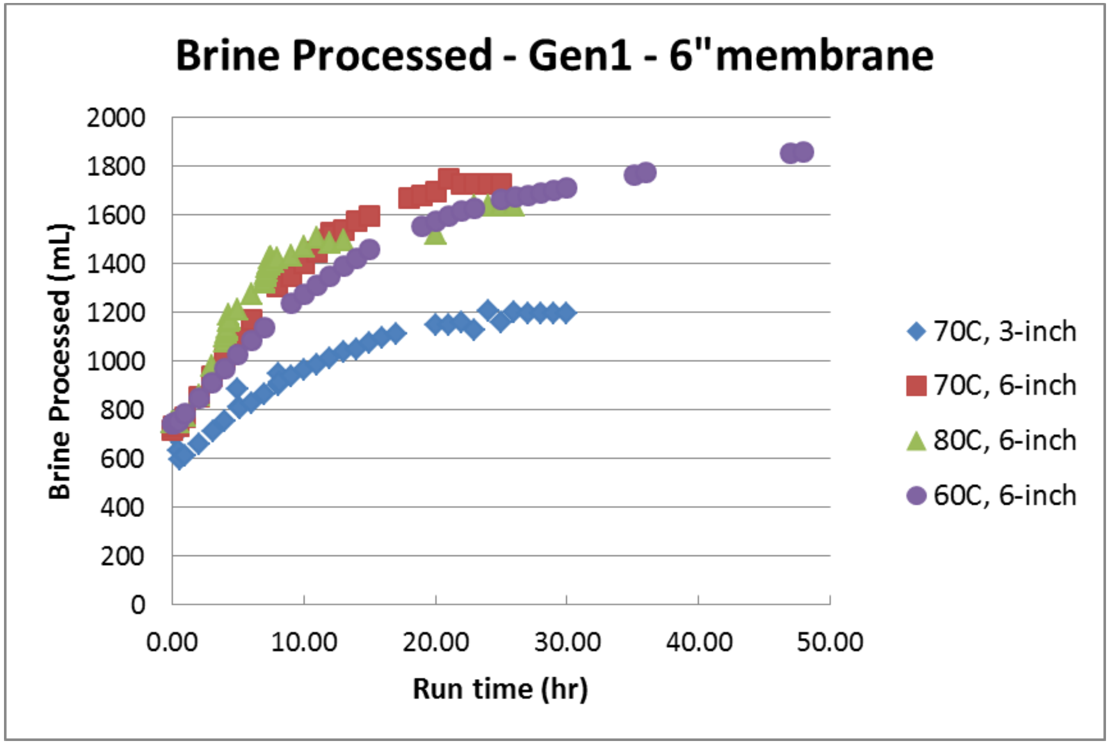
Diffusional Effect

- Gen1 (0.75L) is twice the depth (volume) of Gen2 (0.375L)
- Gen2 was designed to look at diffusion effect
  - None observed
  - Mixing is occurring
    - Gravity effect
- BEB System can process ~2 times its volume in brine
  - Continuous-fill not practical
    - Same ESM
    - Increased Risk



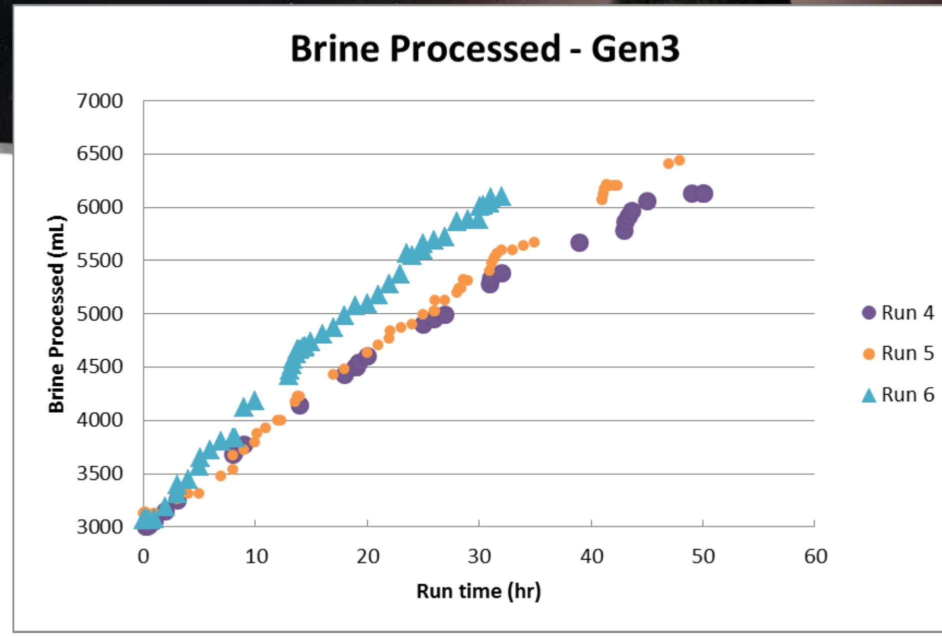
Temperature Effect Gen1

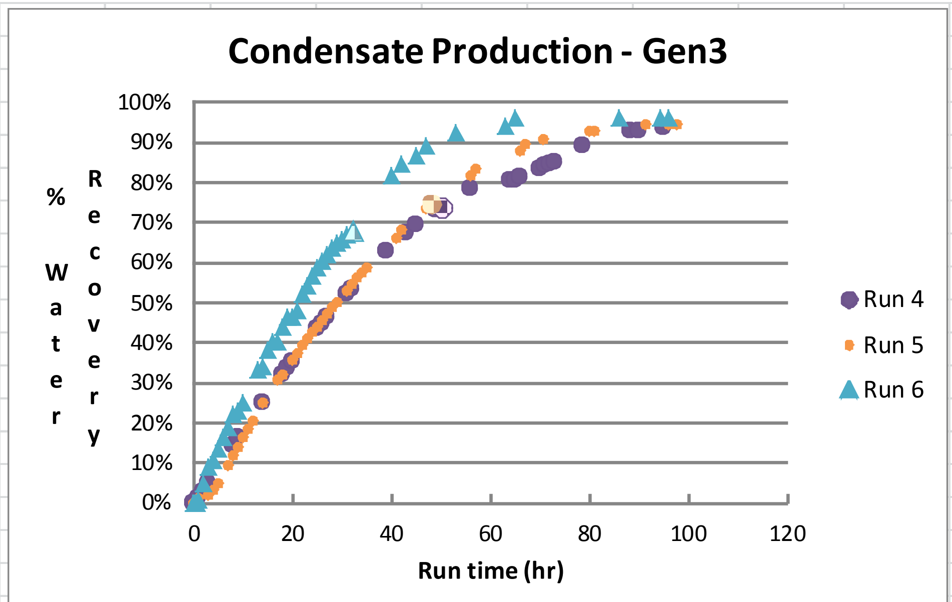
- Hour 1 is identical during warmup
- Higher temperature has an increased rate of dewatering
- Higher temperature has a decreased processing volume
  - Increased dewater rate means diffusion is less important resulting in higher concentration at the membrane
  - Increased temperature results in increased scale formation
- Comparing the 70C 3" and 6" runs show that the production rate increases with membrane area



Temperature Effect Gen3

- Gen3 Data
  - Brine Processed
    - 2x Evaporator Vol
    - 6+ L processes
  - % Water Recovery
    - >95% WRR
- Processing conditions can be varied to meet requirement
  - Higher temp gives higher processing rate
  - Higher temp may limit the processing capacity
- 100% WRR obtainable with Brine Residue Solidification



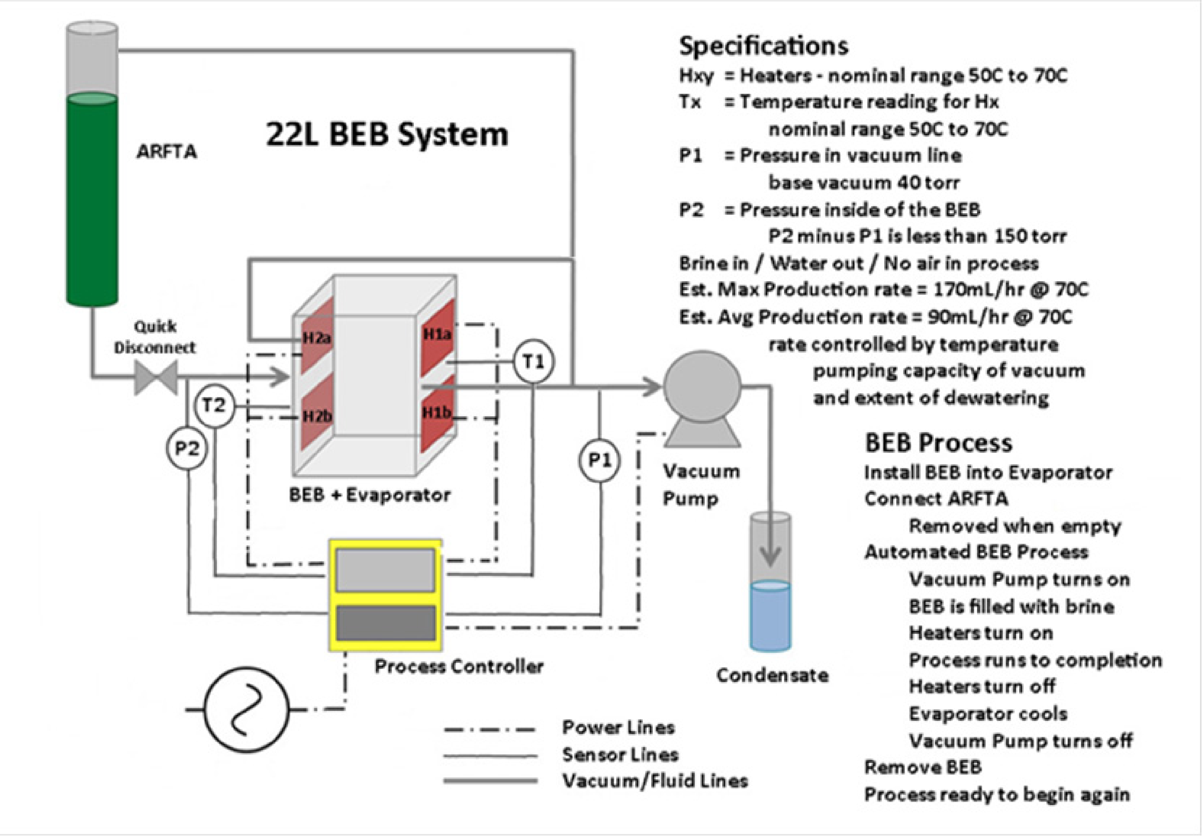


Run	Temp Base	Temp Lid
4	60	50
5	70	58*
6	70	60

* Equilibrium temp due to heating from the base

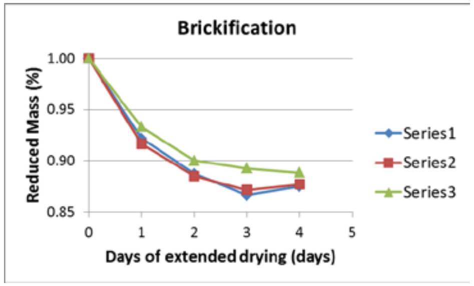
Continuous-fill BEB System?

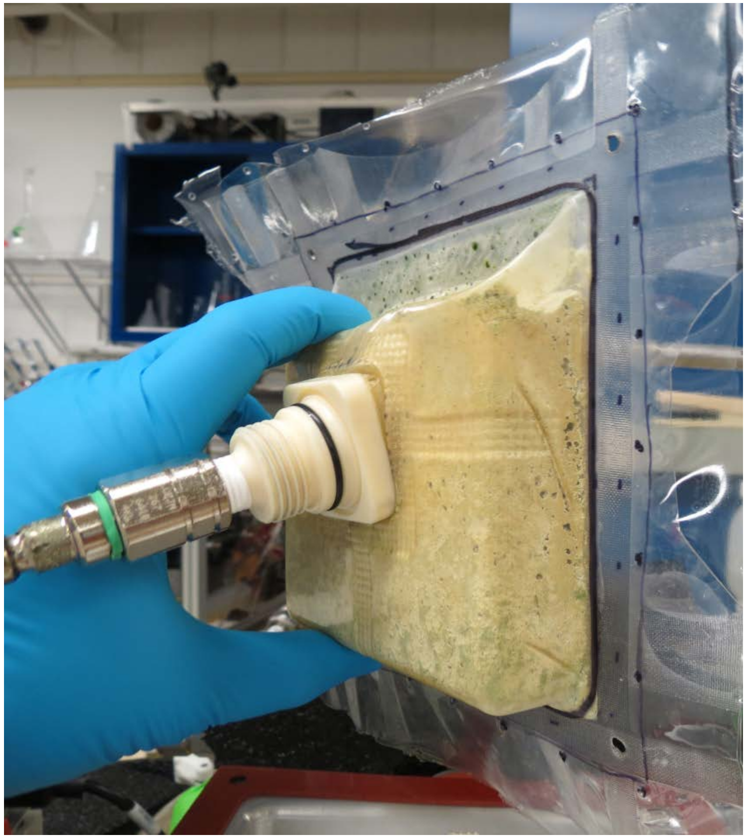
- The Continuous-fill BEB System processes only twice its volume of brine.
- This minimal volume savings is offset by the increased complexity and mass of the continuous-fill process. (data not shown)
- Thus a 22L Batch process is recommended.



Solidification of Brine Residue

- Solidification obtainable with 3 additional days of processing past normal end point
  - Recovers the last few % of water
  - Safens the Brine Residue
    - Residue is a solid
    - No liquid to leak





Solidification Recovers More WATER

- 3 years Mars mission with a crew of 4 produces 1095L of brine
- Brine is 60 to 65% water by mass, containing nominally 700L of water
- Air Evaporation Systems can achieve approx. 80% water recovery leaving 140L of water in the brine
- The BEB System can achieve nominally 100% water recover because of the active heating and drying
  - Leaves only 1 water molecule per 100 acid molecules
    - Dryer than the common rock
- The extra 140kg of water recovered is greater than the ESM mass of the BEB System

Scaling for ISS Batch Mode

- The Gen3 Continuous-fill BEB System as tested is capable of fulfilling the ISS application
  - 11” x 11” x 2.5” in size
- The GenX version could leave up to 2 weeks per cycle for maintenance and other tasks

	Volume		Max Rate	Day per
Gen	Processed	Hours/run	mL/hr	24L Batch
1	1.5	48	85	32
3	6	96	120	16
X	24*	192**	169***	8
* An additional Quadrupling of the BEB's size				
** Calculated as a doubling of the run time				
*** Calculated as a 41% increase in the max rate				

Chemical Analysis Gas Phase

- The BEB System has no tangible gas phase component
  - No carrier/sweep gas
  - 4 mL/day of gas from seal leakage
- Gas Phase analysis is actually the equilibrium headspace over the liquid condensate
  - The liquid phase is the important analysis

Chemical Contaminant	Room Air	BEB Process
	(mg/m3)	(mg/m3)
Chloromethane	<0.025	Trace
Methanol	Trace	0.190
Acetaldehyde	0.120	0.210
Ethanol	Trace	0.083
Acetone*	0.097	6.4
Propanal	0.027	#
2-Propanol	<0.025	Trace
2-Butanone	<0.025	Trace
Pentanal	0.035	<.025
Hexanal	0.078	<0.025
Heptanal	0.041	<0.025
Octamethylcyclotetrasiloxane	Trace	0.990
Decamethylcyclopentasiloxane	0.410	0.420
Dimethyl Disulfide ~	<.050	0.790
Hexamethylcyclotrisiloxane $~	0.780	3.100
Allyl Methyl Sulfide ~	<.050	0.060
Methyl-2-Propenyl Disulfide ~	<.050	0.094
Octanal ~	0.066	<.050
Total Alcohols + Acetone	0.12	0.66
Total Concentration	1.7	12
(Non-methane hydrocarbons)		
Volume of gas		4 mL/day
Trace Amount detected is sufficient for compound identification only		
* GC/FID data results are in italics		
$ Response factor generated from an internal study		
~ Concentrations are estimates only		
# Concentration included in acetone due to matrix interference		
The combined concentration is predominantly acetone		

Chemical Analysis Liquid Phase

- Most of the organics from the BEB are within the liquid condensate
  - 191 ppm
- Most of the metal can be identified as coming from either the aluminum BEB evaporator or the stainless steel tubing

Chemical	Concentration	Chemical	Concentration
Name	mg/L	Name	mg/L
Ammonium	1.97	Methyl disulfide	400
Total S	4.3	Methyl sulfone	494
Calcium	0.22	Benzoic acid	921
Magnesium	0.52	Phenol	2750
Potassium	0.05	4-Methylphenol	9720
Sodium	0.19	Dibutylphthalate	385
Aluminum	32300	Diethyl phthalate	8
Chrome	23	Ibuprofen	400
Copper	11	(+)-Neomenthol	130
Iron	484	2-Phenylacetic acid	180
Manganese	219	Thymol	39
Nickel	29	Ethanol	2760
Selenium	20	Methanol	4460
Zinc	85	Urea	1090
Acetone	47100		
2-Butanone	156	TOC	191000
Acetaldehyde	720		(191 ppm)

System ESM Parameters

- System configuration is for a stand alone system
- If connected directly to the UPA, mass, power and volume decrease
  - Mass reduces 34% to 55 kg
  - Power reduces 72% to 37 W
  - Volume reduces 33% to 0.16 m^3

ESM	Mass	Average Power	Volume	Crew Time
Item	Kg	W	m^3	minutes
BEB				
BEBs	26		0.07	
Spares	2		0.01	
BEB Evaporator	19		0.08	
Vacuum Manifold	8			
BEB System Power		37		
Pump				
Scroll Pump	26		0.07	
Pump Spares	2		0.01	
Pump Power		94		
Crew				
Crew time/cycle				65
Maintenance/year				60
Total	83	131	0.23	N/A
(W/O Pump) Total	55	37	0.16	N/A

Mars Forward

- For a Mars mission, the BEB System could be connected directly to the UPA System eliminating the need for the stand alone vacuum system and the release of organics into the cabin as is currently planned for the ISS
  – Estimated Mars ESM: 55kg, 37W, and $0.16m^3$
  – TOC Released to Cabin of 0.0 ppb
- Brine Residue is a solid (No leakage)

Conclusion

- ESM showed that continuous-fill processing was not preferred to batch mode
- BEB System can easily satisfy the ISS brine dewatering requirements
  - 22L System requires only an est. 8 days out of a 22 day cycle
  - Demonstrated 100% brine containment
  - Demonstrated 100% water recovery
- System ESM for a 3 year mission to Mars including resupply and spares
  - W/ pump: 83kg, 131W, and 0.23m^3
  - W/O pump: 55kg, 37W, and 0.16m^3
- Recovers more water than other technologies
  - 140kg more water recovered for a 4 person, 3 year mission compared to a system only capable of 80% water recovery
- JSC Wyle GCMS liquid analysis showed only a handful of chemical with a total TOC of 191ppm
- JSC Wyle GCMS gas analysis is trivial since the BEB System produces a liquid product and only 4 mL/day of gas (seal leakage)
  - BEB System does not vent into the cabin as other system do