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Chromium Brine Containment Membrane Demister for the CapiBRiC

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The development of a microgravity air-evaporation urine-brine dryer that releases its effluent gas into the cabin of the International Space Station will require some form of a demister to guarantee that no acid, chromium, or other hazardous materials are released within the effluent gas stream. A hydrophobic membrane demister can be used for this application, and can be compatible with the proposed high flow rates of the effluent gas stream. This paper describes the construction and sizing of such a membrane demister.

Nomenclature

BCT = Brine Concentrator Technology
BEB = Brine Evaporation Bag
CapiBRiC = Capillary Brine Residual in Containment
ePTFE = expanded Polytetrafluoroethylene
ISS = International Space Station
IWP = Ionomer-membrane Water Processor
MAPTIS = Materials and Processes Technical Information System
NASA = National Aeronautics and Space Administration
TDS = Technology Down Select

I. Introduction

THE International Space Station (ISS) is currently running at a water deficit. In order to make up for this deficit, water must be periodically resupplied from the earth to the ISS. While resupply is an option for the ISS, on a journey to Mars, water resupply is not feasible. Therefore, it is essential to close the water loop to eliminate the need for water resupply. To close the water loop, the National Aeronautics and Space Administration (NASA) is currently developing two brine dewatering systems, the Capillary Brine Residual in Containment (CapiBRiC)[1] and the Ionomer-membrane Water Processor (IWP)[2].

Both the CapiBRiC and the IWP are air-evaporation urine-brine drying systems that are designed to release their effluent gas into the cabin. The release of the effluent gas into the cabin has the potential to carry small suspended brine particles, which could be composed of pH 2 Cr(VI), into the cabin air which the astronauts breathe.

During the 2015 Brine Concentrator Technology (BCT) Technology Down Select (TDS) meeting,[3] it was discussed how a release of residue from a brine processor could be detected. The proposed detection method was to monitor the conductivity between two closely spaced meshed screens. This method of monitoring the effluent gas for release of bulk amounts of brine could work, however, entrained particles smaller than the gap between the two wire meshes would not be detected. Additionally, small entrained particles, smaller than the mesh size of the screen could actually make their way through the two mesh screens and be released into the cabin.

The proposed system is a small-pore membrane demister that can be used to greatly reduce the possibility of brine release within the effluent gas of these brine processors. The membrane could catch nanometer sized droplets and particles, and if a major brine release event occurs, the membrane would prevent the release of the brine to the cabin because of its hydrophobic nature. This would allow time for detection and the system to be shut down.

This paper will focus the membrane demister application on the CapiBRiC system, but is also applicable to the IWP or any other air evaporation system that releases effluent gas to the cabin.

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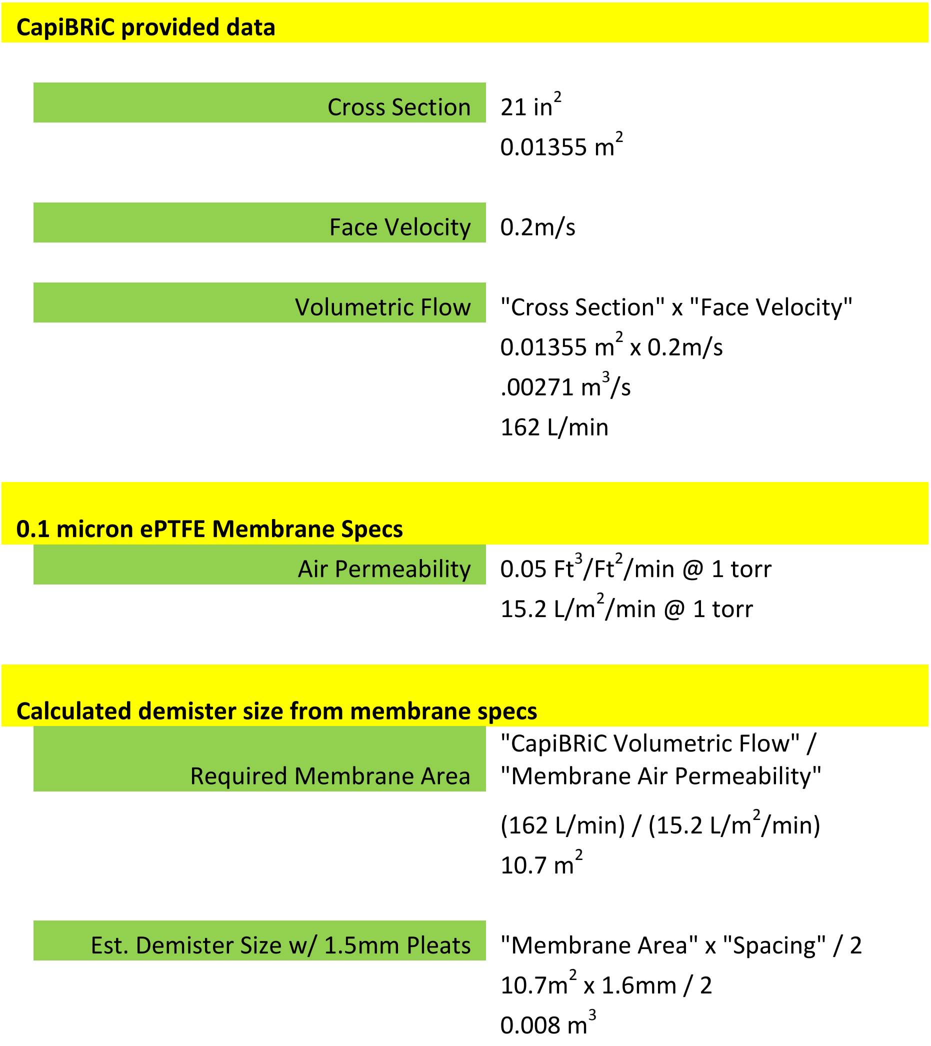
II. Experimental, Results, and Discussion

The CapiBRiC is a brine dewatering system that uses capillary action and surface tension forces to keep the brine adhered to a support structure. Air is then passed over the liquid surface of the brine to sweep away the water vapor as it evaporates. However, in the event that droplets of brine should break free of the surface, these droplets would also be swept away in the air flow and potentially blown into the cabin air that the astronauts breathe. To mitigate this scenario, a membrane demister can be used to filter the entrained droplets out of the air. The advantage of a membrane demister over a standard filter is that the pore size of the membrane is generally smaller (down to 50 nm pore size), and a membrane can be pleated to give a larger surface area (lower pressure drop) per volume.

From the specification received from the operations of the CapiBRiC and the specifications of the 0.1 micron expanded Polytetrafluoroethylene (ePTFE) membrane used (the membrane used within the Brine Evaporation Bag (BEB) system) ,[4,5] an initial calculation was performed to see if a membrane demister could theoretically meet the needs of the CapiBRiC application. This data is presented in Table 1.

Table 1. Calculated demister size for the CapiBRiC at a pressure drop of 1 torr.



CapiBRiC provided data	
Cross Section	21 in^2 0.01355 m^2
Face Velocity	0.2m/s
Volumetric Flow	"Cross Section" x "Face Velocity" 0.01355 m^2 x 0.2m/s .00271 m^3/s 162 L/min
0.1 micron ePTFE Membrane Specs	
Air Permeability	0.05 Ft^3/Ft^2/min @ 1 torr 15.2 L/m^2/min @ 1 torr
Calculated demister size from membrane specs	
Required Membrane Area	"CapiBRiC Volumetric Flow" / "Membrane Air Permeability" (162 L/min) / (15.2 L/m^2/min) 10.7 m^2
Est. Demister Size w/ 1.5mm Pleats	"Membrane Area" x "Spacing" / 2 10.7m^2 x 1.6mm / 2 0.008 m^3

Table 1 shows that a 0.1 micron ePTFE membrane could be built into a demister 0.008 m^3 in volume with a 1 torr pressure drop across the membrane. Continued discussions with the CapiBRiC led to a refined CapiBRiC air flow rate of 116 L/min (compared to the 162 L/min calculated in Chart 1) which is used throughout the rest of this paper.[6]

The CapiBRiC is assumed to use an air flow of 116 L/min and requires an ultra-low pressure drop across the membrane (zero pressure drop, if possible) since fans are used for air flow (from discussion with the CapiBRiC lead). The flow characteristics of a membrane are such that sizing of the demister (membrane area and demister volume) should be linear with the flow rate. The following data should be valid for a 0.1µ ePTFE membrane (Figure 1) using flow rates from nominally 20 to 500 L/min (and probably higher).

A. Membrane Test Stand

Figure 2 shows the membrane test stand that was built . The test stand held a flat sheet membrane with a cross-sectional membrane area of 40 in^2 (8 in x 5 in). A 0–100 torr pressure transducer was used for pressure measurements. The flow rate was measured using a flow meter. The experiment incrementally increased the flow rate, and the system pressure reading and flow rate were recorded. The subsequent flow rate per square foot of membrane was calculated. From this, the required membrane area to support 116 L/min flow was calculated as well as the volume of the demister to hold the membrane in a pleated design. The data is presented in Table 2.

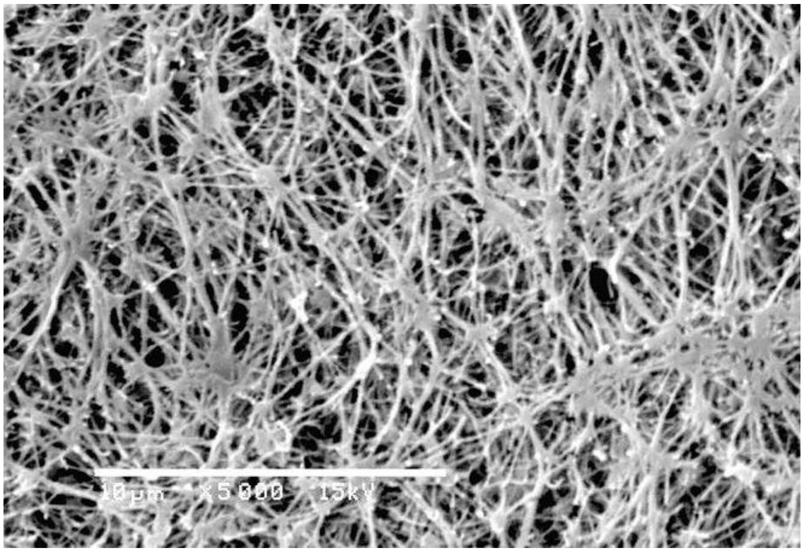


Figure 1. Micrograph of a 0.1 micron ePTFE membrane. Bar in image is 10 microns. Reproduced with permission from Sterlitech.

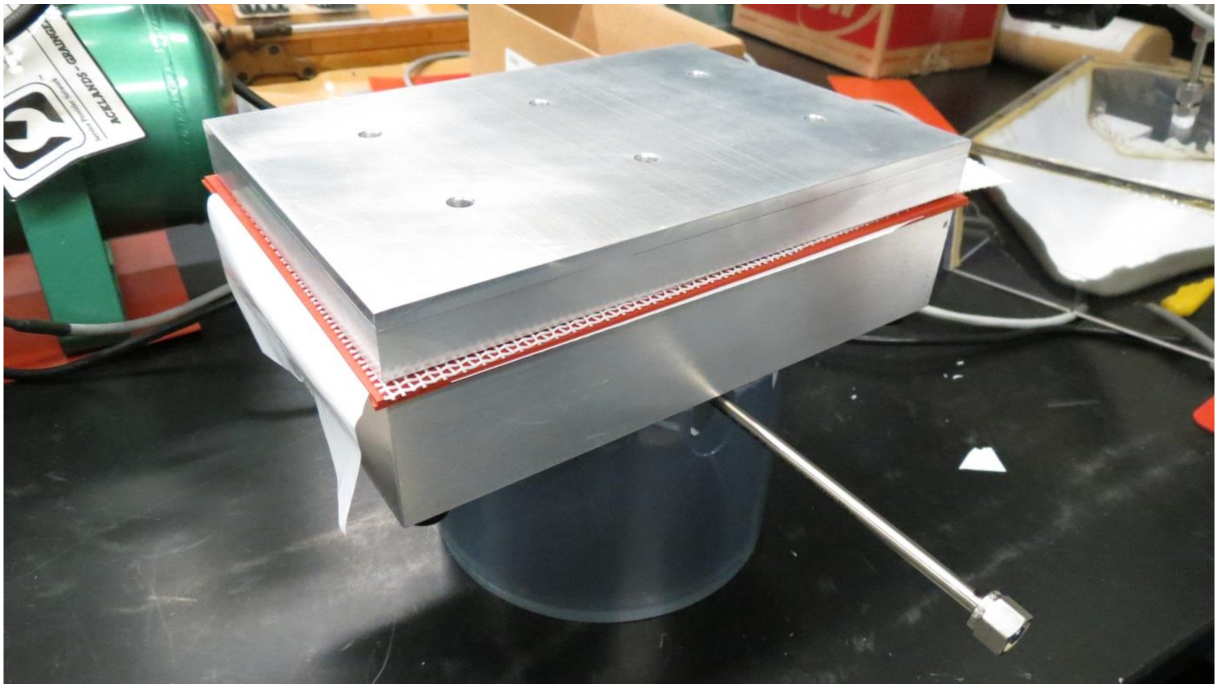


Figure 2. Membrane test stand. Flow goes in the bottom. The membrane is sealed in the middle. The outflow is on the top

Table 2. Membrane Test Stand data showing pressure drop and demister size relative to system gas flow rate.

Gas Flow	Pressure Drop	Demister Permeability	Membrane Area for 116L/min flow	Demister Size for 116L/min flow
L/min	torr	L/min/m^2	m^2	m^3
0.5	0.48	19.4	6.0	0.0190
1	0.98	38.8	3.0	0.0095
1.5	1.46	58.1	2.0	0.0063
2	2.02	77.5	1.5	0.0047
2.5	2.52	96.9	1.2	0.0038

Table 2 shows that a demister with a 1 torr pressure drop sized for the flow of the CapiBRiC would only be approximately 0.01 m^3 (1/3rd ft^3).

B. Brassboard Demister

A brassboard model was built to test the sealing method of construction of the demister. The preferred method of sealing the membrane into the demister is to use a slow-setting, low-viscosity casting material which will strongly adhere to both the membrane and the enclosure. For this study, a polyurethane casting material was chosen for its ability to wet the membrane, adhere to the Plexiglas of the enclosure, and retain a soft, flexible condition after setting up so as to not damage the membrane.

The edges of the membrane were potted using two different polyurethane casting materials to seal the edges of the membrane to the enclosure. The brassboard model is shown in Figure 3. The data obtained using the brassboard model is presented in Table 3.

The data obtained for the brassboard demister agrees with the data obtained from the test stand. The brassboard demister also demonstrated that the method of sealing the membrane into the demister was valid.

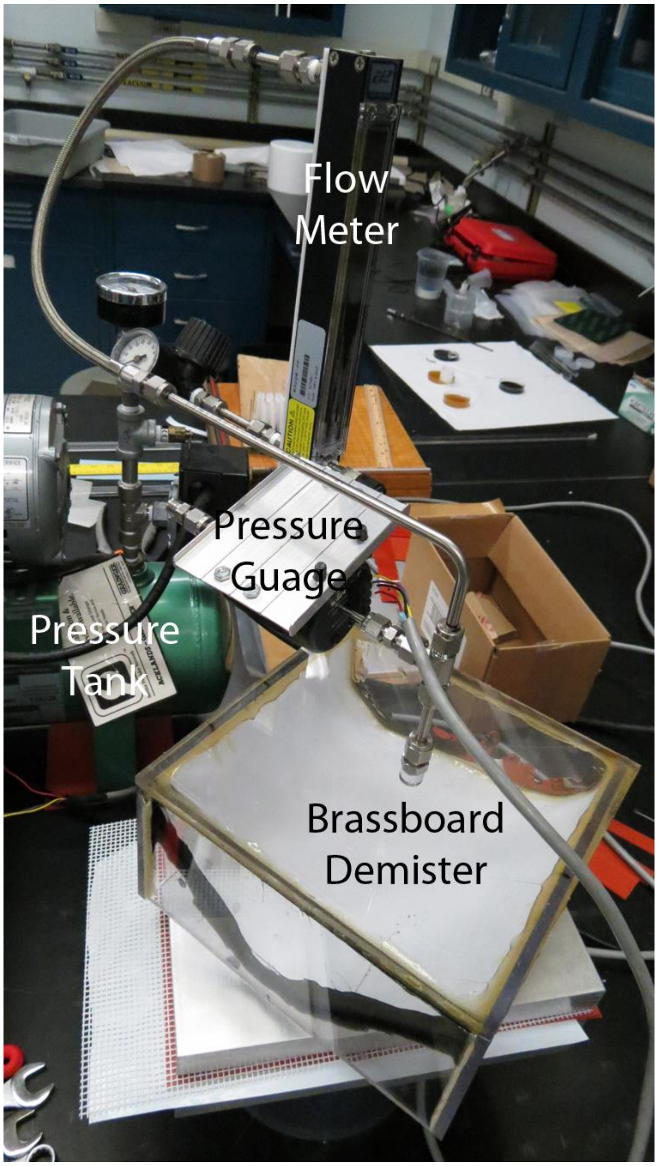


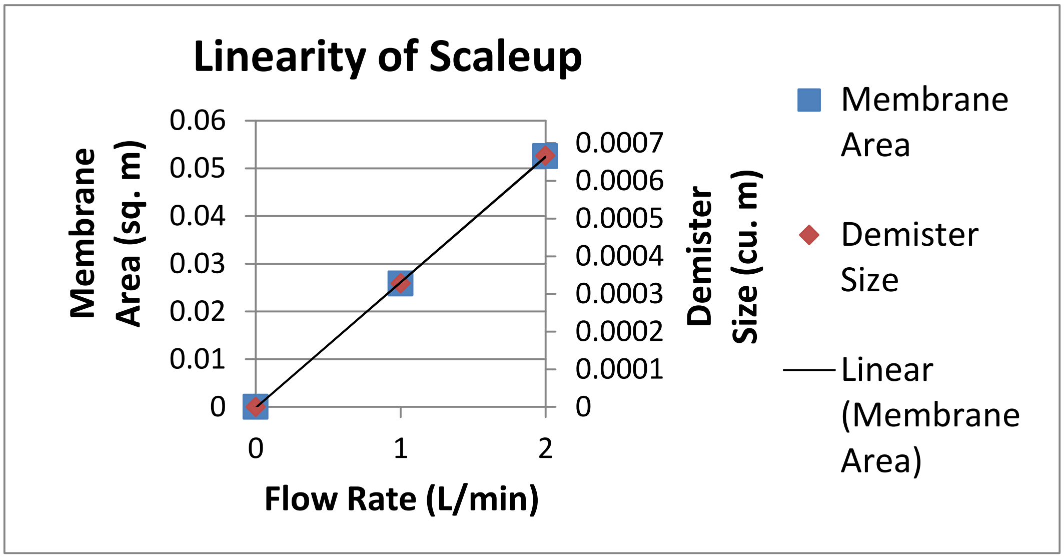
Figure 3. Brassboard demister. Showing the functional elements: air source, flow meter, pressure transducer, and membrane sealed into the demister enclosure.

Table 3. Brassboard Demister data showing pressure drop and demister size relative to system gas flow rate.

Gas Flow	Pressure Drop	Demister Permeability	Membrane Area for 116L/min flow	Demister Size for 116L/min flow
L/min	torr	L/min/m^2	m^2	m^3
0.5	0.24	9.5	12.2	0.0386
1	0.48	19.0	6.1	0.0193
1.5	0.72	28.6	4.1	0.0129
2	1.00	38.1	3.0	0.0097
2.5	1.28	47.6	2.4	0.0077

C. Linearity of Scale-up

Comparison of the data from the Membrane Test Stand and the Brassboard Demister show a linear scaling of the membrane area and membrane demister size versus the system flow rate. The data for a pressure drop of 1 torr is plotted in Figure 4, which shows a linear increase in the membrane area and demister size with increasing flow rate.



Data Source	Flow Rate	Membrane Area	Demister Size
	L/min	m^2	m^3
	0	0	0
Test Stand	1	0.0258	3.28E-04
Brassboard Demister	2	0.0525	6.67E-04

Figure 4. Plot of the membrane area and demister size versus system flow rate showing the linear scale-up of a membrane demister.

D. Polyurethane Potting Material

The two polyurethanes tested (and used for the construction of the brassboard demister) were a low viscosity, low durometer (shore 20A), fast setting (5 min working time) polyurethane (tan in color) and a higher viscosity, medium durometer (shore 40A), slower setting (20 min working time) polyurethane (black in color). For the construction of the brassboard demister, the faster setting polyurethane appeared to work better because of the faster setting time. However, further testing showed that the slower setting polyurethane is actually preferable. Figure 5 shows images of how the two polyurethanes are able to flow and penetrate into a test construct for potting the membrane. Figure 5 (left) shows that the fast setting polyurethane has insufficient work time to allow it to flow in between the membrane and the sidewall of the petri dish; however, figure 5 (right) shows the slower setting polyurethane, although it has a higher reported viscosity, is able to flow in between the membrane and the sidewall of the petri dish. Additionally, Figure 5 shows a strip of membrane which was dipped into the slow setting polyurethane and allowed to "drip dry". The image shows that the polyurethane well wets the membrane, and that the polyurethane is well-adhered to the membrane even after mechanical abrasion and tugging at the polyurethane trying to remove it from the membrane.

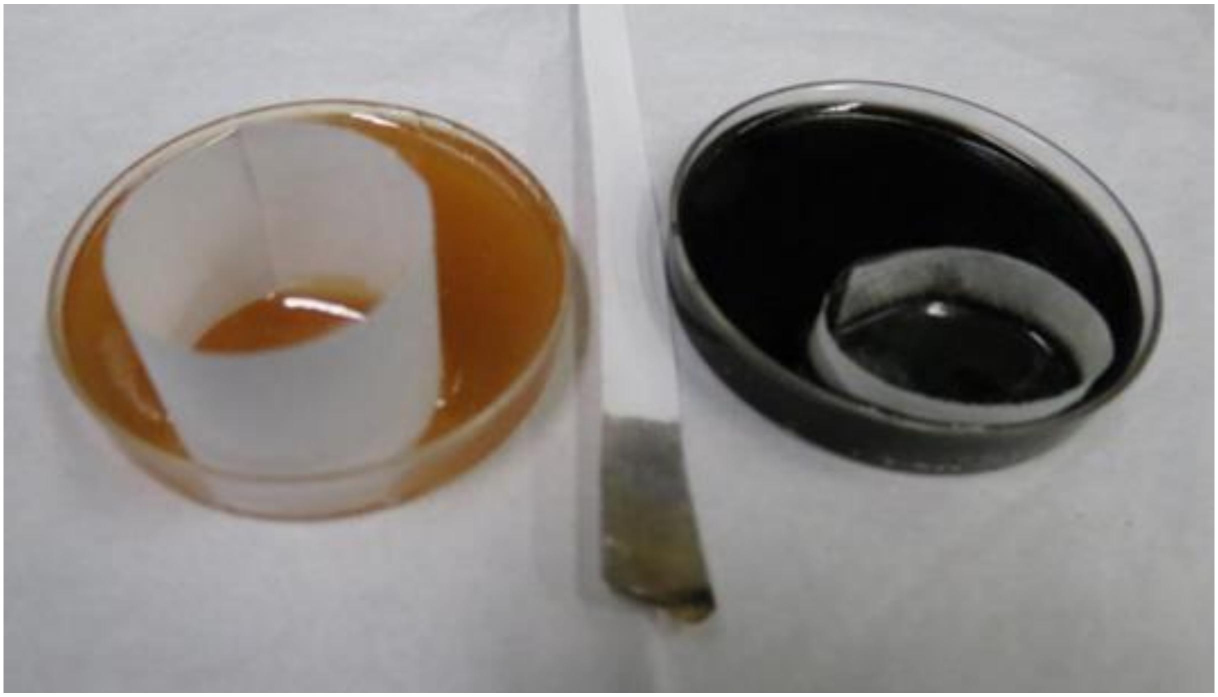


Figure 5. The fast setting polyurethane (tan, left) and the slow setting polyurethane (black, right). In the middle is a strip of membrane which was dipped into the slow setting polyurethane showing wetting.

E. Membrane Demister Model

A 1in x 2in x 3in model with 3.5 pleats of a 3" x 11" membrane was built to demonstrate the construction of the membrane demister (Figure 6). The limited size of the membrane demister was due to the 8" x 11" membrane sheets which were on hand. The model shows the recess at the top and bottom in which the membrane is inset and then backfilled with the polyurethane casting material to pot the membrane. The construction of a full-sized demister will require the special ordering of a membrane roll to have the required length.

The membrane demister would be an independent element of the CapiBRiC system, not part of the CapiBRiC brine containment "bag". It is estimated that one demister would work over numerous operation cycles if not the entire life of the CapiBRiC. The exact lifespan of the demister will depend on the degree of particle entrainment or brine release events of the CapiBRiC system.

F. ISS Application

The application of this system to the ISS still needs further refinement. The selection of polyurethane as the potting agent for the membrane was simply chosen because it was readily available. However, the selection of polyurethane as the potting material may need further investigation. Polyurethane generally has a high degree of outgassing, and as such is generally not a good material for ISS applications. Although, HYSOL™ US0118 is a two-part polyurethane, which according to the Materials and Processes Technical Information System (MAPTIS), has an "A" rating for outgassing and toxicity in ISS applications. An "A" rating means it is acceptable.

The membrane demister would be an integral part of the system and not the individual brine bags used for dewatering the brine. As such, it is expected to last for numerous runs; however, it may or may not last for the entire duration of the mission. In order to determine the end of life of the membrane demister, a differential pressure gauge could be used to measure the pressure drop across the membrane, and if the pressure drop became too great, the demister would need to be replaced. This pressure drop measurement would work for determining the end of life if the filter gets plugged by suspended particulate matter within the cabin air, the membrane gets plugged from suspended brine droplets which may be accumulating on the membrane over multiple runs, or a catastrophic event occurs.

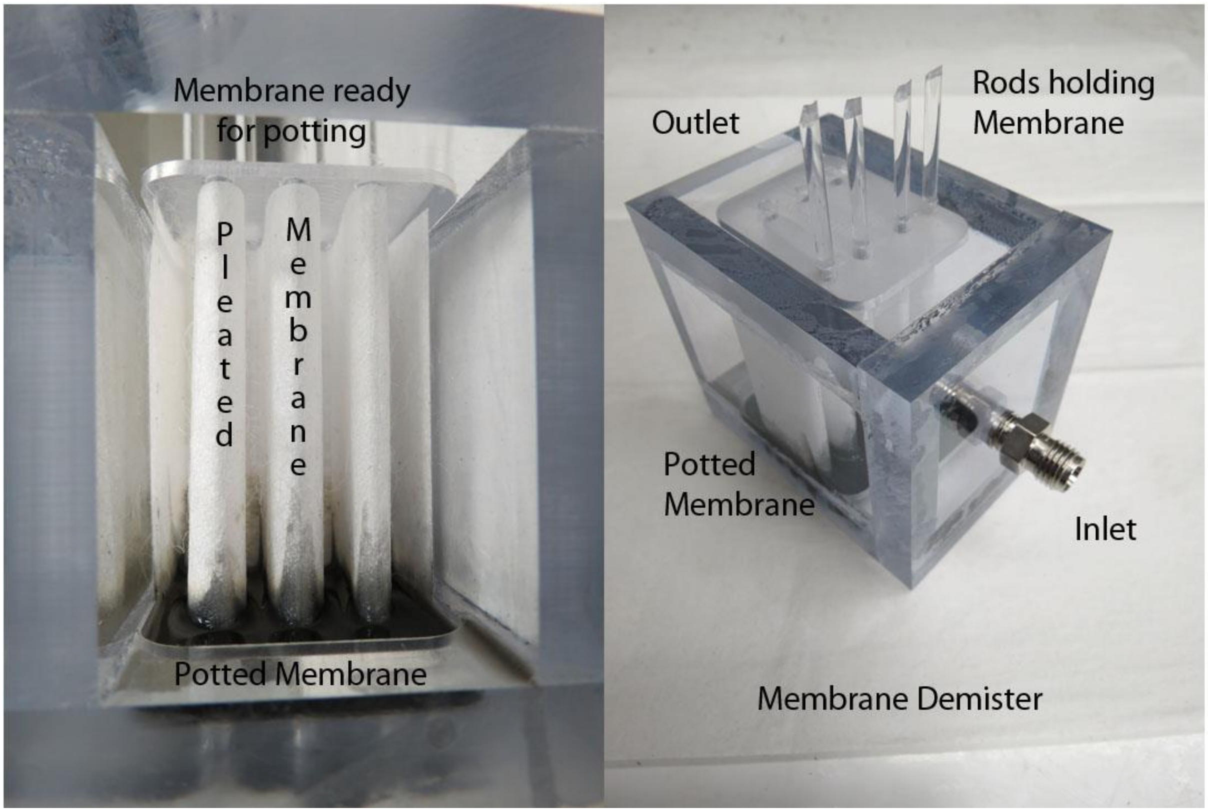


Figure 6. Model demonstrated the construction of the membrane demister.

III. Conclusion

A membrane demister capable of handling the estimated effluent flow from the CapiBRiC with an ultra-low pressure drop is feasible to design and build. The flow capacity and construction methods have been demonstrated.

The membrane tested was a 0.1 micron ePTFE membrane and allowed a flow rate of 38 L/min/m^2 (3.5 L/min/ft^2) at a 1 torr pressure drop. The membrane demister size scales linearly in volume to the flow rate of air and requiring only 0.008m^3 (0.3 ft^3) per 100 L/min of flow. With this capacity, the membrane demister not only is suitable for use as a demister for the CapiBRiC, but could also be designed to work with the much high flow rate of the IWP.

Acknowledgments

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