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Habitat Water Wall for Water, Solids, and Atmosphere Recycle and Reuse

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Abstract

The membrane water wall concept proposes a system for structural elements that provide, thermal, radiation, water, solids and air treatment functions that are embedded into the walls of inflatable or rigid habitats. It provides novel and potentially game changing mass reduction and reuse, along with additional structural advantages over current mechanical life support hardware, structural materials, and radiation protection functions. The approach would allow water recycling, air treatment, thermal control, and solids residuals treatment and recycling to be removed from the usable habitat volume, and placed in the walls by way of a radiation shielding water wall. It would also provide a mechanism to recover and reuse water treatment (solids) residuals to strengthen the habitat shell. Water wall treatment elements would be a much-enlarged version of the commercially available hydration bag. Some water bags would have pervaporation membranes facing inward, which would provide the ability to remove H_2O, CO_2 and trace organics from the atmosphere. This paper provides the results of experimental work evaluating the performance of the X-Pack™ hydration bag to treat simulated wastewater and solid wastes and determine the maximum water recover ratio that can be achieved.

Nomenclature

WATER POSITIVE = Water Protection with Overall System Integration Inside Vehicle Envelopes
FO = forward osmosis
DI = deionized water
OA = osmotic agent
CTB = crew transfer bag
ISS = International Space Station
D-RATS = Desert Research and Technology Studies
HUD = Habitat Demonstration Unit
DTO = detailed test objective

VOC = volatile organic carbon

I. Introduction

The cost of human space exploration has become prohibitive. It is a major impediment to the frequency and duration of current and future missions. What is needed is a radical departure from the status quo, one that would allow the cost of human spaceflight to be reduced by an order of magnitude. To do this will require a new approach to sustaining humans in space. This paper describes such an approach where life support, thermal, structural, and radiation protection functions are integrated into the walls of the spacecraft. It achieves a mass savings by combining the function of radiation protection, thermal control, and life support functions within the mass allocation of a radiation protection water wall.

Water is an excellent radiation protectant. It is likely that any future long duration human missions will require radiation shielding and the use of water will be one of the leading candidates. For instance, for a Mars transit mission a 30 cm thick water wall increases the allowable mission duration by 20%, based on maintaining total exposure below allowable exposure limits (50 cSv) [1]. Water is also crucial to providing life support functions and thermal control. By combining these functions, multiple requirements can be met and a significant mass savings can be recognized.

For instance, in its simplest form WATER POSITIVE would use a radiation protection water wall to store fresh water and wastewater. This would provide mass savings by eliminating the need for a separate set of water tanks and the water to fill them, assuming a water wall is used for radiation protection. For a one-year mission, the water alone required to meet metabolic and hygiene requirements would weigh in excess of 100,000 kg/person in an open loop worst-case scenario [2]. In addition to mass and radiation savings, water can be recycled in a water wall by integrating membrane based water treatment systems. Similarly, it is possible to provide air treatment, solid waste treatment, and thermal control within the water wall. This approach allows life support functions to be removed from the usable habitat volume and placed within the walls, potentially eliminating a sizable portion of the mass, volume, and some power consumption of traditional standalone systems. This would provide a mechanism to recover and reuse water treatment (solids) residuals to strengthen the habitat shell. Furthermore, it would potentially result in a more passive and therefore more reliable system than the current state-of-the-art, which is mechanically complex. It is called the Water Protection with Overall System Integration Towards Inside Vehicle Envelopes (WATER POSITIVE) project.

II. Background

Ideally, the WATER POSITIVE water wall would be composed of a series of membrane bags packed as dry elements integrated into an inflatable habitat structure wall. After launch and deployment, the wall would be filled with water and would be maintained as a freshwater supply and radiation shield. As the initial water supply is consumed, the depleted treatment bags are filled with wastewater and take on a dual role of active forward osmosis (FO) water treatment and water wall radiation shielding. Figure 1 shows an artist's rendition of how a system might look when integrated into the walls of an inflatable structure.

FO is a natural process where the osmotic potential between two fluids of differing solute/solvent concentrations equalizes by the movement of solvent from the less concentrated solution to the more concentrated solution. Typically, this is accomplished through the use of a semi-permeable membrane that separates the two solutions, and allows the solvent to pass through the membrane pores but not the solute. This flux of solvent across the membrane continues until the osmotic potential across the membrane and solute/solvent concentrations begin to equalize.

When an FO element is exhausted, fouled, and/or stalled by excessive waste side residuals, treatment ceases in that element, and the treatment element function is then passed on to the next bag in the wall. Exhausted FO bag elements are drained, fluids are then mixed with feces, solid organic wastes, and/or advanced water treatment residuals, are re-injected for sludge treatment, or simply cured in place to a stable solid.

Figure 1. Inflatable habitat structure showing inner liner layers and the location of FO bag elements. Original images by John Frassanito & Associates, Courtesy of NASA by way of http://library.thinkquest.org.

Exhausted bags now work as organic/solids composting digesters/driers. Anaerobic digestion will produce CO_2 and CH_4, which will be harvested, compressed and processed for use in O_2 generation. Methanogenic composting will stabilize the bio-solids, producing humus. The bio-solids will then be dried using low-pressure ventilation of the bio-solids.

Nitrogen rich urine dominated brines, typical of a transit mission waste profile, combined with thermally stabilized solids (charcoal and/or ash) would be aerobically treated to drive off ammonia and odor causing VOCs to be dried to a “sheet-rock” like material in place. Once the humus or urine salts (sheet rock) are biologically stable, the bags become a permanent hydrocarbon/hydrated precipitate radiation shield.

Air treatment in a spacecraft is traditionally composed of the functions of thermal control, humidity control, CO_2 control, and trace contaminates control. All of these functions can be accomplished to some extent by contacting cabin air with a water wall element constructed with a gas permeable membrane. Such a water wall element would be separate from the water/solids treatment wall element described previously.

Humidity control is commonly accomplished in a spacecraft by the use of a condensing heat exchanger. A condensing heat exchanger operates by reducing the dew point of a gas such that water vapor condenses out of it and the resulting gas achieves a targeted relative humidity as it leaves the exchanger. Membrane-based condensers can be used as condensing heat exchangers [3]. These membrane condensers can be adapted to use the osmotic potential of salt water across a hydrophilic membrane to cause water vapor to condense.

The approach proposed for use in the water wall is a combination of both thermal and osmotic differences. Osmotic pressure differences are used to control latent energy and condense water out of the atmosphere, while thermal control is used to control sensible energy and maintain the cabin air at a specific temperature. In this process, water on one side of a membrane is maintained at a specified temperature and the osmotic potential is adjusted to condense water out of the air, which is in contact with the other side of the membrane. The liquid water is then treated in a desalination system, which is returned to the water wall at the appropriate temperature and osmotic potential to repeat the process in a continuous cycle. The water removed in the desalination system is then treated to potable water standards.

Carbon dioxide is sparingly soluble in water. However, once solubilized, CO_2 can either be converted to carbonic acid (depending on the solution pH), adsorbed by liquid amines, or adsorbed by other liquid or particulate adsorbent materials in solution. Thus, a water/membrane gas contactor can be used to strip CO_2 from cabin air as long as the carbonate ions are removed at a rate in proportion to the solubility restricted diffusion rate of CO_2, which requires some pH control. The key to such a process is to provide enough gas/liquid contact area to address the low solubility and diffusion limits of CO_2 in water. The membrane water wall provides an ideal construction for such an interface as the inside surface area of the habitat is quite large.

Levels of semi-volatile compounds in a spacecraft atmosphere can be controlled by contacting it with liquid water. In such a construct, the maximum level of a given semi-volatile compound in the atmosphere can be calculated by the Henry's Law constant associated with the compound. If the liquid concentration of the compound is kept low by processing the compound through a bioreactor, catalytic reactor or adsorbent bed, this disequilibrium between the liquid phase and gas phase will strip semi-volatile organics from the atmosphere. Some semi-volatiles with boiling points below water will not be completely removed so a secondary biological or physical chemical system may be required.

Volatile organic carbon (VOC) removal may be accomplished by photo-catalysis. The inner liner of the inflatable habitat will be made of a woven silk material impregnated with titanium dioxide. Titanium dioxide is a photo-catalyst under ultraviolet (UV) light and when doped with nitrogen ions or tungsten trioxide it is also a visible light photo-catalyst [4]. The inner walls of the habitat provide enough surface area to treat most volatile organics even if conversion rates are low. The light source is the interior lighting of the habitat. The impact of day/night illumination on atmospheric VOC concentrations will have to be evaluated and there may be a need for supplemental biological or physical chemical VOC removal capability.

An alternative approach is to use a membrane incased algae bioreactor segment of the water wall to strip CO_2 and convert it into O_2. Bio-air scrubbing has been used in industrial air pollution control and most particularly odor control for some time [5]. Models for trace contaminant control can be projected based on these industrial air pollution control systems. However, the technology of gas exchange membranes is also well developed and can be applied as well. Such a system could be very effective, but would likely require re-supply of nitrogen as the amount of nitrogen available in the waste model is not enough to support full CO_2 conversion requirements. However, nitrogen is normally lost from the atmosphere due to spacecraft leakage and EVA, so re-supplying it as a fertilizer may offer benefits when compared with tanked high-pressure gas.

The WATER POSITIVE concept brings together a number of technologies, who's purpose is a new approach to supporting humans in space. Some of these technologies are well established and have been extensively tested. Others are currently under development and have only received limited testing. However, none of these technologies has been tested as an integrated system. As result, the WATER POSITIVE concept can be considered speculative and subject to all of the development risks inherent with that of new technologies and concepts. WATER POSITIVE is a research project rather than a specific technology. Ultimately, the final configuration that defines its performance will be determined by the results of future experimental programs. This paper presents the results of one set of experiments designed to provide an evaluation of the feasibility of dewatering simulated spacecraft wastewater brines and feces.

III. Experimental Program

Development of this system and the many subsystems required to achieve full functionality of the WATER POSITIVE concept is a significant undertaking. The approach being used to manage the scope of this activity is to evaluate each function at the bench scale, and then to scale up to a sub-function prototype before attempting to develop an integrated system. To this end, a series of experiments was completed in order to evaluate the ability of the forward osmosis process to dewater a simulated ersatz solution representing spacecraft wastes. The objective of this testing was to evaluate whether the technology could treat wastewater, and then dewater wastewater residuals and solid wastes prior to further chemical/biological solid waste processing in the water wall architecture. In addition, tests were performed to evaluate the reduction in performance, which occurred as the bags were reused multiple times. To complete this work, a commercially available forward osmosis technology called the X-Pack^{TM}, available through Hydration Technologies Inc., was used.

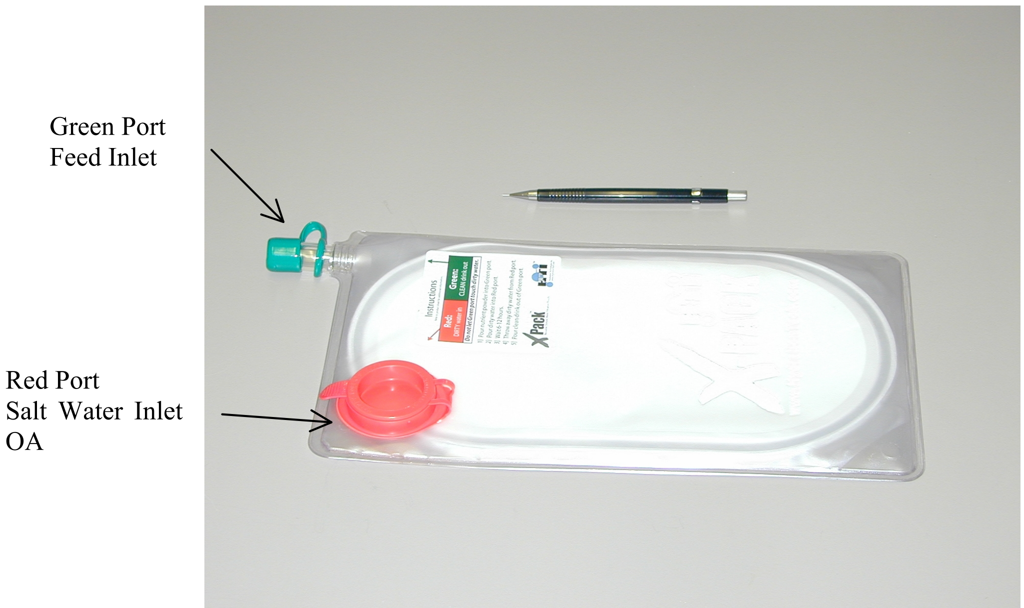

Figure 2. Hydration Technologies X-Pack^{TM} Forward Osmosis Treatment Bag. Note reverse orientation of feed and product. The commercial version is designed to be used with wastewater placed in the red port and product taken from the green port. For this testing, the feed is placed in green port, and product is removed from red port.

The Water Wall X-Packs^{TM} were tested on a three to four day weekly schedule. One side of the membrane was filled with simulated wastewater ersatz solution, as shown in Table 1, and the other side of the membrane was filled with simulated salt water, 35 g/L of NaCl in deionized water. The wastewater ersatz was placed in the green port and the salt water was placed in the red port. For the first test bag, 70g/L of NaCl solution was poured in the red port side of the X-Pack^{TM} and 1000 mL of ersatz mixture was poured on the green port side.

Volumetric data were then collected every two hours in a six-hour run time with a final data point at 24 hrs. Decreases in the volume of the feed on the green port side of the membrane were used to calculate the flux rate. Red port side measurements were only measured at the beginning of each day's run and end of the run. At the end of each day's run, the X-Pack^{TM} was re-charged by pouring 500 mL of fresh NaCl solution in the red port side, which was then left overnight. The green port side was not re-charged until the following day just before starting the run.

Solid waste tests using simulated human feces ersatz mixture and the byproduct brine of the wastewater tests were also completed. The solid waste/byproduct ersatz, shown in Table 2, was poured in the green port side. These tests used a 300g/L NaCl solution on the red port side and data was collected once a day. The draw solution was recharged one time during the run with a fresh 300g/L NaCl solution, which was poured into the red port.

For the wastewater tests, each bag was reused 10 times for a total of 30 runs completed using 3 different bags. For the solid waste tests, the 3 bags used in the wastewater test were used. Each bag was used on one multi-day solid waste dewatering test.

IV. Experimental Procedure

A. Preparing Liquid Ersatz:

1) Label three 1 liter flasks C1, C2, C3 and add 500 ml of deionized (DI) water to each. For each concentrate, add the ingredients listed in the Ersatz Wastewater Formulations for Testing Water Recovery Systems paper for each respected concentrate, Table 1 [11]
2) Mix ingredients until each has gone into solution. Dilute each flask to 1 liter with DI water and mix thoroughly. Cap all concentrates and store under ambient conditions
3) 1 liter working solution: Add 300 ml DI water, 100 ml of concentrate 1, and 100 ml of concentrate 2 to a 1-liter flask and mix thoroughly then add 100 ml of concentrate 3 and dilute with DI water to 1 liter and mix thoroughly

Table 1: Recipe Used for Wastewater Ersatz Mixture [6]

Concentrate 1 (10x)- Organics	**Target Wt**	**Concentrate 2 (10x)- Inorganics**	**Target Wt**	**Concentrate 3 (10x)- Humidity Condensate**	**Target Wt**
Urea	52.021g	Sodium Chloride	23.126g	Acetic Acid	0.441mL
Creatinine	5.221g	Magnesium Chloride Hexahydrate	5.483g	Benzoic Acid	0.0464g
Histidine	0.958g	Potassium bicarbonate	2.197g	Benzyl Alcohol	0.259mL
Taurine	0.556g	Potassium hydrogen carbonate	0.474g	Ethanol	1.506mL
Glutamic Acid	1.660g	Potassium monobasic phosphate	1.069g	Acetone	0.030mL
Glucose	2.636g	Potassium Chloride	5.436g	Caprolactum	0.191g
Ammonium Citrate	12.340g	Potassium Sulfate	7.424g	Phenol	0.027g
Ammonium Formate	1.466g	Calcium Chloride	0.221g	N,N-Dimethylformamide	0.035mL
Ammonium Oxalate Monohydrate	0.665g	Sodium Sulfate	4.144g	Ethyl Glycol	0.157mL
				Formaldehyde	0.461mL
				Formic Acid	0.208mL
				Lactic Acid	0.187mL
				Methanol	0.218mL
				1,2-Propanediol	0.013mL
				2-Propanol	0.042mL
				Propionic Acid	0.042mL
				Urea	0.101g
				4-Ethyl Morpholine	0.072mL

B. Preparing Solid Waste Ersatz

Mix together 2 X chemicals listed in Table 2 to represent solid waste ersatz using a blender while adding 100 mL of DI water to each batch of measurements (Total DI water: ~150 mL to 200 mL) to achieve thick liquid consistency. Measure (measure what? mass?) final ersatz mixture, cover with parafilm and store in fridge.

Wait until approximately 1L of reject brine is accumulated from test bag runs. Dilute the solid ersatz mixture with reject brine to achieve appropriate liquid consistency so that a funnel can be used to pour it in green port side of x-Pack. Make sure air is out of bag before closing. Once this is complete, the bad is ready for testing.

Table 2: Recipe Used for Solid Waste Ersatz [7]

Component	Target Wt
Peanut Oil	20g
Spirulina	30g
Calcium Chloride	30g
Potassium Chloride	40g
Sodium Chloride	40g
Cellulose	15g
Polyethylene glycol	20g
Psyllium	5g
Miso	5g
Dried Biomass	50mg

C. Experiment Bag Test Procedure

This procedures applies to all test bags. However, for solid waste tests, skip steps 1-4? Additionally, for the solid waste tests, only the OA is measured every two hours and recharged with different NaCl concentrations in three to four day increments (i.e. 70, 140, 300 g/L).

1) Add 100 ml of concentrate 1 into 100 ml flask
2) Add 100 ml of concentrate 1 into 1000 ml flask (ersatz mix)
3) Add 100 ml of concentrate 2 and 3 into same 1000 ml flask
4) Fill to flask to 1000 ml mark with DI water
5) Add 70 g/L of NaCl into 1000 ml of DI water in separate volumetric flask
6) Pour 500 ml of NaCL mixture into the red port of X-Pack
7) Pour 1000 ml ersatz mixture (or solid waste?) into green port
8) Every two hours, measure green port side of bag using volumetric flask and return samples back to x-pack green port using funnel
9) Calculate flux rate and recovery ratio
10) Test three bags
11) Complete at least 10 runs in each bag

V. Results

The results of experimental testing for three bags are presented in Figures 3 through 7. Figure 3 shows the production rate or the flux of water through the internal membrane of the bag, in units of liters per meter square per hour (L/m^2 hr), as a function of time. In the Figure 3, the flux rate for wastewater ersatz runs decreases with time, which is due to the increase in concentration of the feed and the dilution of the osmotic agent solution over time. All three bags performed similarly, with minor exceptions. Figure 4 shows the same type of data but for the solid waste ersatz. This solution performs in a similar manner to the wastewater ersatz tests except that the initial flux rate is much lower due to the high osmotic potential of the solid waste ersatz. The flux rate declines slightly due to fouling of the membrane. The spike in flux at about 5 hours is an artifact of the recharge of the NaCl draw solution during the run.

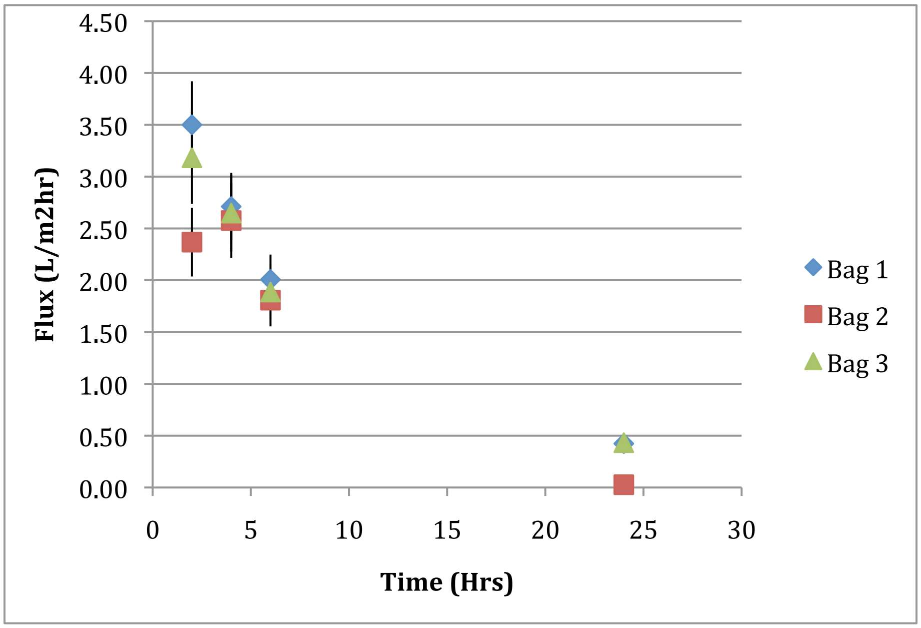

Figure 3. Flux testing for bag 1, 2, and 3. Each data point is the average of 10 runs in each bag. Error bars range from 5% to 14%.

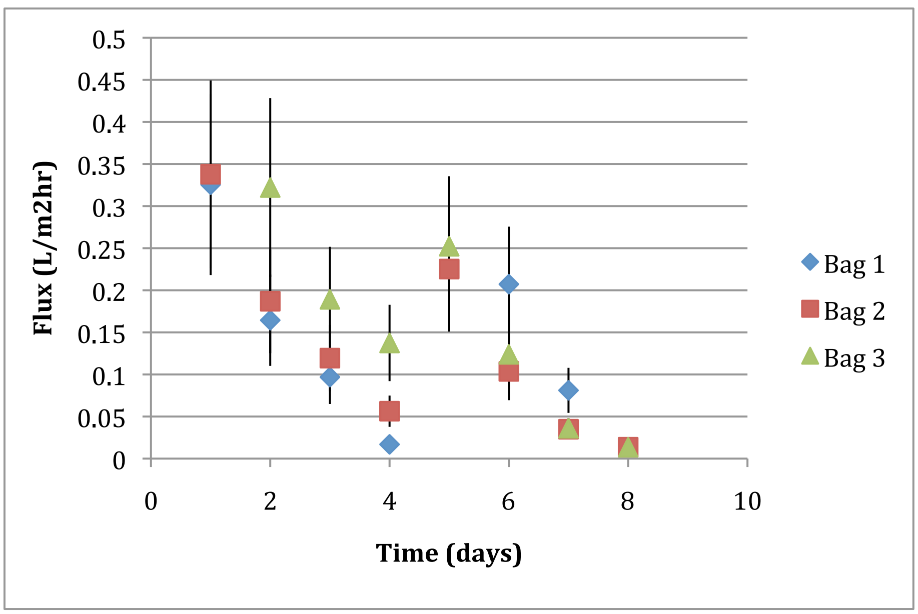

Figure 4. Flux testing for solid ersatz. Each data point is the average of 8 runs in each bag.
Note: at about 5 hours the OA was recharged. The resulting spike in flux can be seen. Error bars range from 5% to 33%.

Figure 5 shows that for the wastewater tests, the flux of water decreases slightly as the bag is reused. Over the 10-bag cycle, the flux declined about 25%. Figures 6 and 7 present the results of the water recovery ratio calculations for the same tests presented in Figures 3 through 5. The water recovery ratio is the ratio of the mass of water in the feed to the mass of water produced. Figure 6 shows that when treating the wastewater ersatz, the bag achieves a water recovery ratio of approximately 90% after 24 hrs. Figure 7 shows the water recovery ratio for the solid waste ersatz. This shows that after 8 days of contact, a recovery ratio of approximately 95% is possible for the solid ersatz. The total water recovery ratio is composed of both sets of data

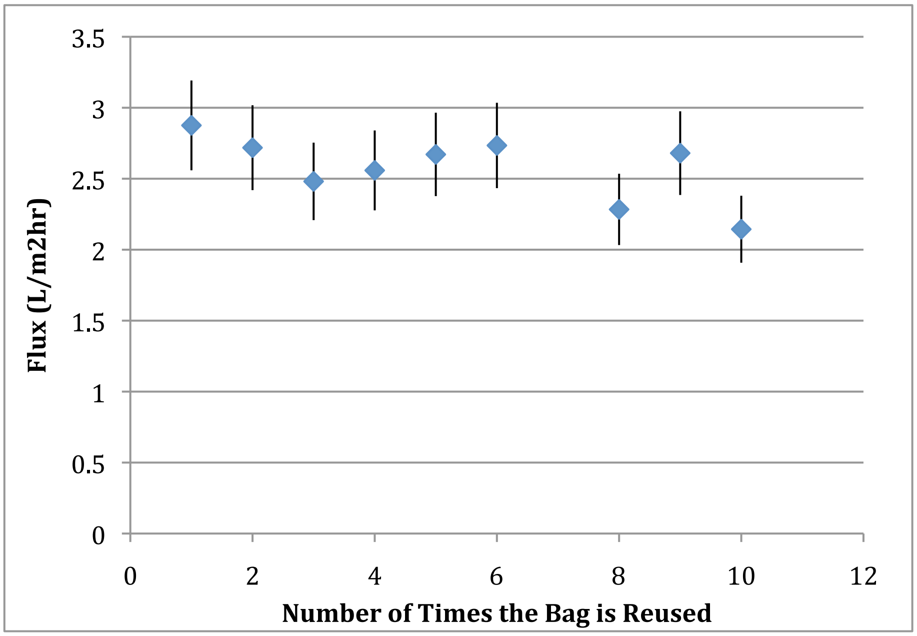

Figure 5. Reduction in flux as a function of the number of times a bag has been reused. Data was taken after 4 hours of operation for each data point. Error bars are +/-11 %.

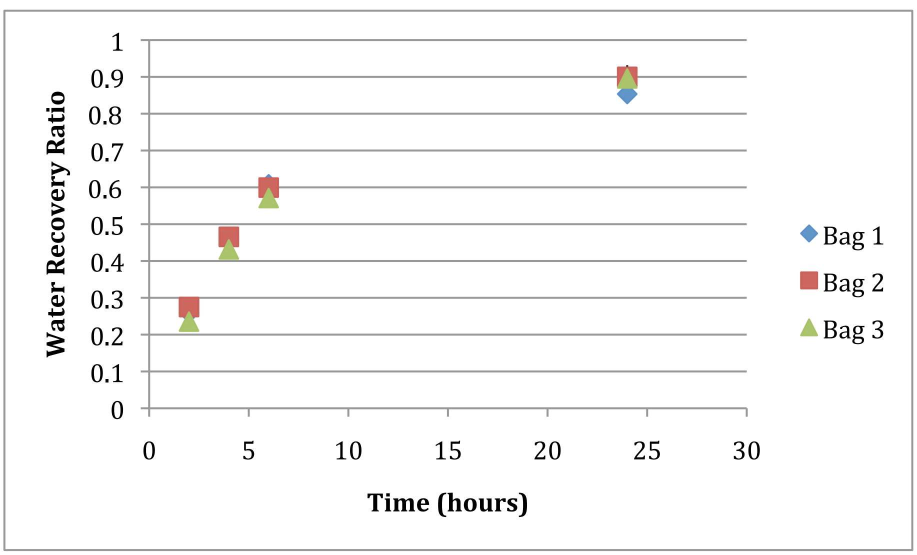

Figure 6. Water recovery ratio as a function of time for ersatz. Each data point is the average of 10 runs in each bag. Error bars are 4 % and cannot be seen.

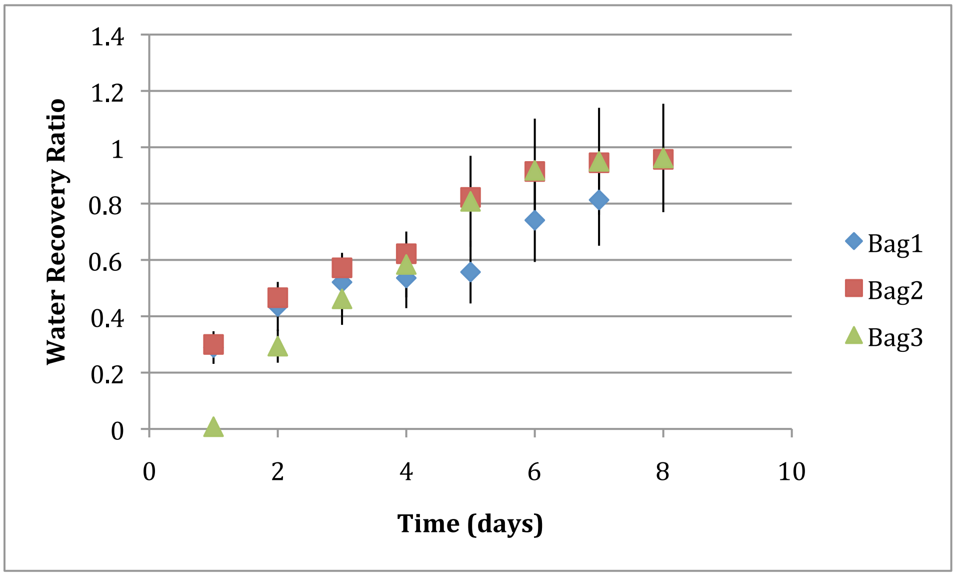

Figure 7. Water Recovery Ratio as a function of time for solid ersatz. Each data point is the average of 10 runs in each bag. Error bars are 20 %.

VI. Conclusions

The results of ersatz wastewater and solid ersatz bag testing show that the concept of treating wastewater in a water wall using FO is possible. The X-Pack^{TM} bags have the fit, form, and function of the water wall membranes proposed for use in the WATER POSITIVE concept. Testing demonstrated the ability to treat simulated ersatz wastewater in an X-Pack^{TM} bag with a water recover ratio of 90%. When mixing the resulting concentrated brine with simulated fecal material, and returning the mixture to the bag, another 95% of the water in the solid ersatz was removed. Therefore, the combined water recovery ratio that can be achieved was over 99%.

The testing also measured flux rate. Flux rates are the rate at which water crosses the FO membrane and is equal to the production rate. It is important as it defines the amount of membrane required to treat the wastewater on a given mission. As shown in Figures 3 and 4, the maximum flux of water in the X-Pack^{TM} is 3.5 L/m^{2}hr when treating wastewater and 0.3 L/m^{2}hr when treating the solid ersatz. It is important to note that flux rates decrease as a function of time. This is because during a run, the feed is concentrating and the OA is becoming diluted. As a result, the osmotic potential difference across the membrane decreases during the run. A run is complete when the osmotic potential equalizes and water no longer flows across the membrane . Measured flux rates were within predicted values and verified membrane sizing assumptions used in Gormly *et al.* [8,9].

The testing also evaluated the reduction in flux that occurs as the bag is reused. Each bag was reused 10 times during this experiment. During each run, solids were formed and some of these solids stayed on the membrane surface. The membranes were rinsed between uses but not cleaned, and no mixing during a run occurred. As the runs proceeded, these solids inhibited the flux of water across the membrane. During these tests the flux rate decreased by about 25% after 10 reuses of the bag.

The results of this experimental testing demonstrate that the concept of a membrane based FO water treatment system integrated into the walls of a water wall is feasible. The system will treat wastewater and achieve a high water recovery ratio. The FO membranes are reusable but their life will be limited as the flux rate decreases with every reuse. Product water purity and post treatment requirements were not evaluated in this work but have been previously evaluated in Gormly *et al.* [8].

VII. Future Work

The development of the WATER POSITIVE concept requires the testing, and integration of many technologies. The approach being used is to evaluate individual technologies or functions in the laboratory, to develop the data necessary to design a full-scale system, and then to evaluate its feasibility. Selection of the final set of technologies used and the integrated system design will be derived from the results of the current experimental program.

The water Positive concept is too preliminary at this time to calculate over all mass, power, and volume parameters. Appropriate performance parameters do not yet exist because the impacts on crew time requirements, interior volume, mass balances, power consumption, projected lifetimes and phasing are poorly understood. Future work will focus on fully answering the questions needed to assess this concept on the basis of mass, power, and volume in microgravity. Some of this work has already been done. The membrane water wall surface area requirements for wastewater recycling for spacecraft applications were described in Gromly *et al.* [8]. This paper defines the maximum water recovery ratio that can be achieved due to osmotic drying. A flight qualified FO bag has been developed and will be tested in space on STS-135, in July 2011. An FO Crew Transfer Bag (CTB) has been developed that shows how a water wall could be integrated to form one large architectural element. This prototype CTB is also being used to demonstrate approaches to filling and draining FO bags integrated into a CTB or future water wall based habitats. This CTB will be tested in a field demonstration project in August 2011. This prototype CTB is shown in Figure 8.

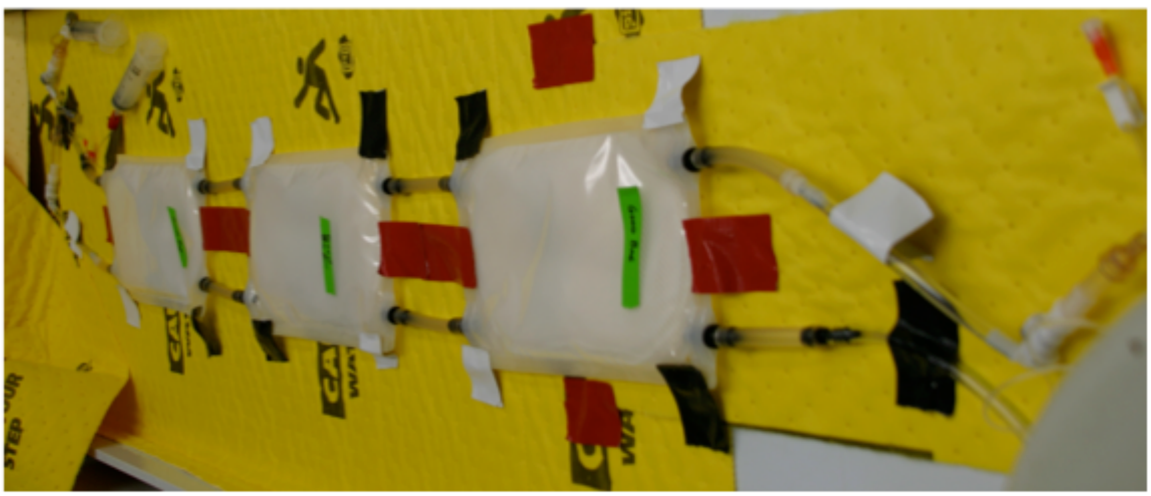

Figure 8 . FO CTB internal bag plumbing layout (prototype configuration)

Integration with CTBs is being pursued to provide a deliverable that will both validate the WATER POSITIVE concept and provide a near term deliverable that could be useful to current space flight missions such as a back up to baseline systems for ISS. This near-term building block approach to developing the water wall is being provided by the incorporation of the FO membrane bag directly into the construction of the CTB and then using the CTBs as proposed by Howe *et al.* [10] to provide flexible habitat building units. In this mode, the membrane elements embedded in the CTBs could be added to the habitat structure as building elements and then networked to provide fluid treatment, eventually ending up as stable permanent wall construction elements.

Figure 9: FO CTB folded into the CTB crew transfer configuration

The CTB in Figure 9 contains a CTB outer envelope with the FO bag incorporated into the layers of the CTB. The CTB outer skin (being waterproof) functions as the outer envelope of the FO bag, providing secondary containment. The FO membrane bags are simply inserted and pleated directly into the CTB bag wall. The whole CTB then becomes an FO water treatment bag. In this way the CTBs, rather than becoming garbage after its primary use, becomes a building block of the life support water recycle and radiation protection system. It also becomes building elements of the habitat itself as described by Howe *et al.* [10]. To understand what this would look like Figures 10, 11 and 12 illustrate this concept. [10].

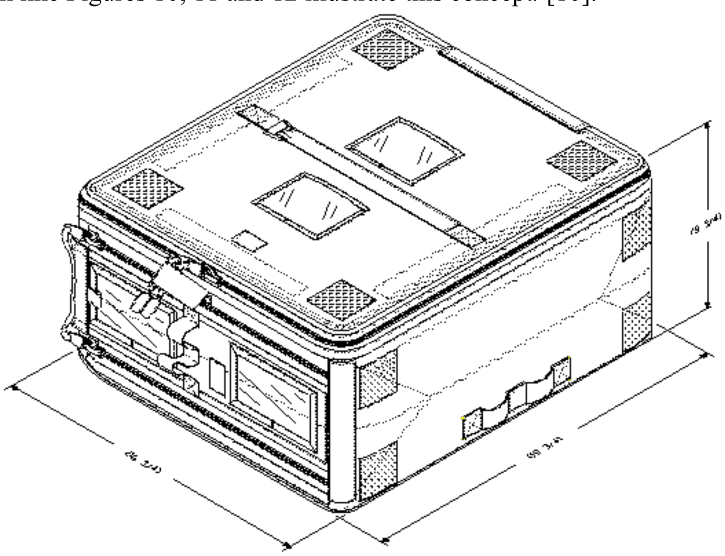

Figure 10: A standard Cargo Transfer Bag (CTB) configured (folded up) to transfer cargo to ISS

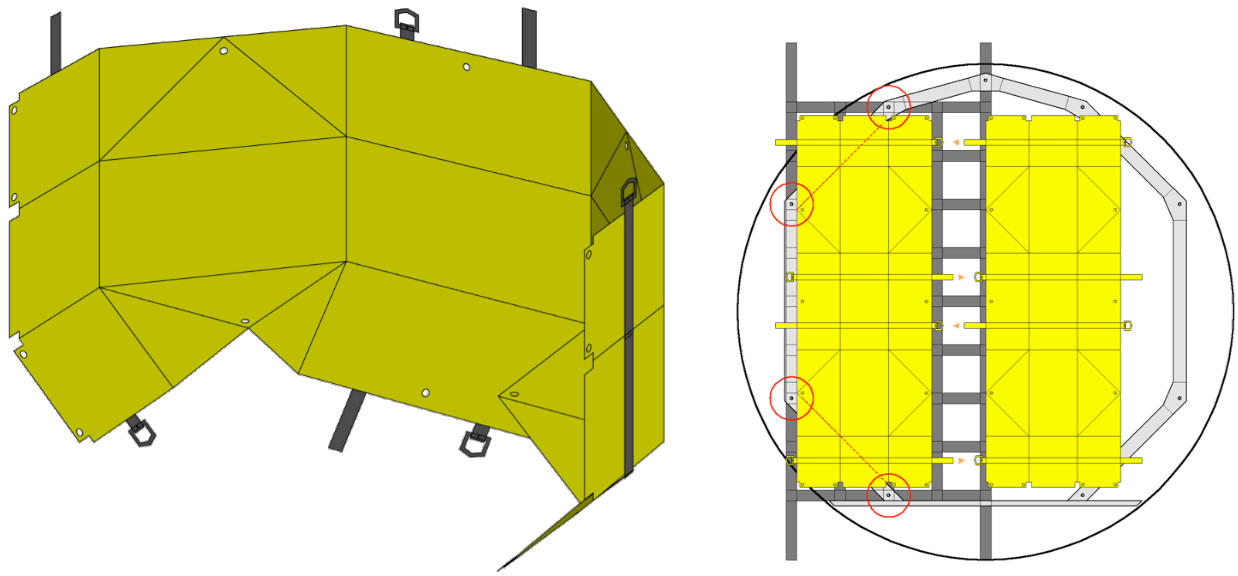

Figure 11: CTB unfolding to form FO CTB a functional panel and installation of panel in habitat .

Figure 12: Unfolded CTBs incorporated into wall elements such as dividers and a chair.

Once the CTBs are used to transfer equipment and are unfolded and mounted as shown in Figure 12, the FO bag based CTBs can provide a backup water treatment system, thus increasing mission reliability. Over time the accumulated CTBs become an ever increasing life support and radiation shielding capability based on what is now garbage (the CTBs) and wastewater treatment residuals (cured material inside).

The CTB prototypes will be tested during the 2011 Desert Research and Technology Studies (D-RATS) simulation. D-RATS is an annual field test led by NASA in collaboration with non-NASA research partners. The D-RATS effort assesses preliminary exploration operational concepts for surface operation concepts. The first demonstration of the WATER POSITIVE CTB concept will occur at RATS in August 2011 when a FO CTB bag will be used to treat wastewater from the Habitat Demonstration Unit (HDU). HDU is a facility simulation of a manned mission to a planetary surface.

The FO CTB bag is also currently under consideration for a NASA directed test objective (DTO) mission sometime after 2013. It is expected that a series of these flight qualified WATER POSITIVE CTB bags could provide microgravity flight demonstrations of individual technologies such as water and waste recycling, thermal control, radiation shielding and in situ structural element development. In addition, they will also result in the deployment of a backup water recycling and radiation protection on ISS.

The first flight test of a stand-alone FO bag is currently manifested to fly as a sortie payload on the final Space Program's Shuttle Mission, STS-135 in early July, 2011. This mission will test a flight qualified version of the X-pack called the Forward Osmosis Bag (FOB). The flight experiment will be conducted post-undocking from the ISS and samples will be returned to the Space Life Science Lab (SLSL) at Kennedy Space Center (KSC) for post-flight analysis. The main goal for Phase I of FOB is to investigate the forward osmosis membrane in spaceflight environment and compare its performance against ground reference controls. The top-level objectives are to evaluate the flux of water across a forward osmosis membrane in reduced gravity using a combination of indicator dyes and to also evaluate the effects of mechanical mixing upon the flux rate.

The second flight testing program will focus on flying more flight qualified X-Pack™ bags with the modified internal membranes to fully quantify microgravity performance. These flights are scheduled to fly as a DTO payload in 2014.

Acknowledgments

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References

[1] Jeng F. A. J. Handford. An Architecture Study for Mars Transit Flight and Surface Missions from Radiation Exposure Perspective, NASA JSC report ESCG-4470-11-TEAN-DOC-0018, 2011

[2] Handford, A., (2002) Advanced life support baseline values and assumptions document, NASA - Johnson Space Center, Houston, TX.

[3] Hapke, J., C. Na Ranong, et al, Temperature and Humidity Control by Means of a Membrane Based Condensing Heat Exchanger, 33rd International Conference on Environmental Systems, SAE Paper # 2003-01-2628

[4] Ao, C. H., S. C. Lee, Indoor air purification by photocatalyst TiO2 immobilized on an activated carbon filter installed in and air claenaer, Chemical Engineering Sciences, Volume 60, Issue 1, 2005, pages 103-109

[5] Togna, A. P., M. Singh, Biological vapor-phase treatment using biofilter and biotrickling filter reactors: Practical operating regimes, Environmental Progress, Wiley, Vol 13, Issue 2, Pages 94-97, May 1994

[6] Verostko, C., Carrier, C., and Finger, B., (2004) Ersatz Wastewater Formulations for Water Recovery Systems, Proceedings of the 34th International Conference on Environmental Systems, Colorado Springs, CO SAE Paper # 2004-01-2448

[7] Wignarajah, W., E. Litwiller, et al Simulated Human Feces for Testing Human Waste Processing Technologies in Space, Proceedings of the 36th International Conference on Environmental Systems, Norfolk, VA. 2006

[8] Gormly, S., M. Flynn, A. Polonsky, Membrane Based Habituate Wall Architectures for Life Support and Evolving Structures. Proceedings of the 40th International Conference on Environmental Systems, Barcelona Spain, AIAA 2010-6073, 2010

[9] Gormly, S., Flynn, M., (2007) Lightweight Contingency Urine Recovery System Concept Development, Proceedings of the 36th International Conference on Environmental Systems, Chicago, Il SAE Publication # 2007-01-3037

[10] Howe, A., Howard, R., NASA Lunar Surace Systems Project (LSSP) Habitation Team members., (2010) Dual Use of Packaging on the Moon: Logistics-2-Living, Proceedings of the 40th International Conference on Environmental Systems, Barcelona Spain, AIAA Publication