

Lightweight Contingency Water Recovery System Concept Development

Sherwin Gormly and Tra-My Justine Richardson
National Space Grant Foundation

Michael Flynn and Mark Kliss
NASA Ames Research Center

ABSTRACT

The Lightweight Contingency Water Recovery System (LWC-WRS) harvests water from various sources in or around the Orion spacecraft in order to provide contingency water at a substantial mass savings when compared to stored emergency water supplies. The system uses activated carbon treatment (for urine) followed by forward osmosis (FO). The LWC-WRS recovers water from a variety of contaminated sources by directly processing it into a fortified (electrolyte and caloric) drink. Primary target water sources are urine, seawater, and other on board vehicle waters (often referred to as technical waters). The product drink provides hydration, electrolytes, and caloric requirements for crew consumption.

The system hardware consists of a urine collection device containing an activated carbon matrix (Stage 1) and an FO membrane treatment element (or bag) which contains an internally mounted cellulose triacetate membrane (Stage 2). All components are light weight disposable plastic, the system is potentially wearable, and it uses no electrical power. When treating urine and other wastewaters containing high levels of organic contaminants this two stage treatment process is required. Seawater and wastewaters containing low levels of organics can be treated for removal of inorganic contaminants (like the salt in seawater) and microorganisms using only the second stage FO membrane element.

First year performance testing indicated acceptable flux rates and water recovery percentages over 6 to 12 hours of optimal urine treatment, when using the full system. Some challenges remained in achieving and evaluating acceptable contaminates flux/rejection rates for TOC and nitrogen species in the product; see ICES paper

2007-01-3037 (Gormly and Flynn, 2007). Year 2 work has focused on four basic areas:

- Characterizing performance of the Stage 2 FO membrane treatment to harvest seawater for use in post landing survival at sea.
- Researching alternative food product and components for use as the osmotic agent (OA).
- Pursuing better TOC confirmation in terms of total expected flux/rejection and characterization. In particular, research to confirm (TOC) flux measured in NaCl/ultra-pure water brine product solutions using high chloride compatible analysis methods.
- Increased nitrogen species control and characterization in the process and product, particularly investigating product side options for urea and/or ammonia nitrogen control.

Of these tasks the first is complete, the second and third are in work with substantial data currently available and reported, and the last is in the initial stages of concept development and data collection.

Concluding comments and discussion will include a synopsis of seawater, urine and technical water recovery concept development as well as some future options for developing this technology. Initially, the system's urine recycle function is intended for contingency/emergency use only, but will do so at a significant mass savings when compared to contingency water supplies and/or conventional water treatments. LWC-WRS Stage 2 can be exploited to provide emergency utilization of seawater and technical waters. Ultimately, further development of the technology may also provide options for better integration of water recycling into larger habitat component design by including FO membrane elements within the structures.

INTRODUCTION

REVIEW OF BASIC LWC-WRS CONCEPTS

The LWC-WRS is a two step process that applies activated carbon adsorption followed by FO (Figure 1). Activated carbon adsorption is enhanced in a saltwater matrix and thus works better in urine and/or seawater in terms of contaminant removal efficiency. These highly contaminated matrices exhaust the adsorption capacity of the activated carbon quickly in comparison to conventional water treatment applications, but provide an extremely effective primary treatment process (particularly for urine).

The activated carbon pretreatment is only necessary for the conditioning of raw urine for FO treatment. Seawater and questionable freshwaters (undergoing minimal or prophylactic treatment) require only the FO treatment step. FO treatment works on the principle of rejecting salt at the membrane while equalizing the osmotic pressure across a hydrophilic water treatment membrane that separates salt from sugar. Organic rejection can be highly dependent on the dominant organic molecular species present, and this is an important specific waste stream based factor in final product quality. However, FO is primarily targeted to inorganic ion and biological pathogen removal in the seawater and technical water process scenarios. Additionally, if the targeted technical water does contain toxic organics at levels of concern, Stage 1 adsorbents can be reintroduced to the treatment package design.

The FO process and X-Pack/SeaPack[®] commercial product hardware, that is utilized extensively in the LWC-WRS concept development and initial testing, is an outgrowth of a long-term SBIR supported project working relationship between NASA Ames Research Center (ARC) and Hydration Technologies, Inc (HTI) of Albany, OR. HTI has produced and is marketing several commercial products variants of this basic technology. These products are all based on the development of effective cellulose triacetate FO membranes. The ready availability of these products have been an instrumental part in the LWC-WRS concept development. However, the commercial product is not necessarily the only hardware format, and is not flight rated in its current construction. Optimization and integration with supporting elements will be necessary prior to fielding the technology as an emergency crew water recovery system.

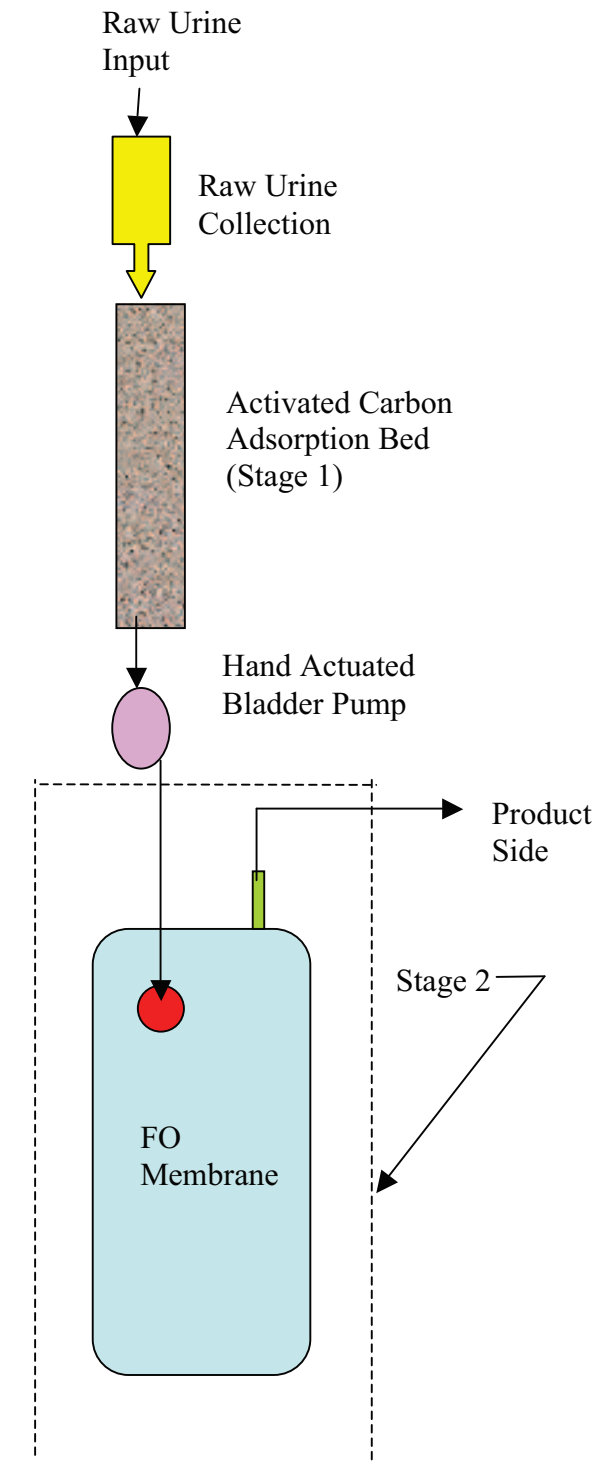


Figure 1: The LWC-WRS system diagram. Urine collection two stage treatment is shown. Seawater treatment requires only the FO Membrane treatment element (inside the dashed line).

OPERATIONAL MODES (ADVANTAGES AND CHALLENGES)

There are three operational modes that are relevant to the use of the LWC-WRS for human space flight emergency water recovery. These are:

1. Urine recovery for reuse during in space contingency scenarios of days to weeks in duration.
2. Seawater recovery in the event of an off nominal CEV (or other water recoverable vehicle) landing at sea and delayed recoveries of 12 hours to 10 days.
3. As a temporary/prophylactic treatment for water resources that are available, but are no longer fully trusted, due to primary treatment system upsets (malfunction) or other failures of primary water sources on International Space Station (ISS), a lunar base, other planetary base, or transit vehicle will all likely have a single conventional water source (tank or recycling system) and failure at that source could be a mission critical failure.

Urine Treatment Option

The full (two stage) LWC-WRS process concept is necessary for urine recovery. The activated carbon and FO membrane urine process can return approximately 75 % of the urine input by volume at a dry weight of 323 g/l of urine processed. Basic required size, weight, water flux/production rate, and recovery rate (percent water recovery) constraints were investigated and reported previously (Gormly and Flynn, 2007). The system can be stored dry for an indefinite period of time and requires no power or vehicle interface to use.

Several treatment quality parameters remain under investigation and optimization. Initial flux and TOC rejection was excellent. However several analysis and performance challenges remain. TOC analyses during early testing was complicated by chloride interference with the TOC analysis method and equipment used. Method development was required to provided higher confidence in TOC performance values.

Also, the initial urea and ammonia values were higher than acceptable, based on food grade targets, in some (though not all) of the initial test runs. Process improvement for nitrogen species control is necessary to guarantee the ability to constantly meet food grade standards for the product.

Seawater Treatment Option

During year two of the investigation, the seawater recovery operation mode emerged as an important near term deployment option. This is partially because it is inherently simpler than the urine recovery option and can be derived more directly from a commercially available and tested version of the HTI product (i.e. the SeaPack®).

The commercially available unit is identical to any flight rated version from a process standpoint, but will require re-fabrication to meet flight standards. This is primarily an outer bag materials issue, and does not effect process performance relevant parts of the FO bag directly. Of more interest for process investigation is the potential reformulation and repackaging of osmotic draw solution to be more valuable as a complete and metabolically balanced food, as well as potentially assist in nitrogen species control. The current seawater product is a bit sweet and may benefit from the addition of other components. It is also shipped as syrup in the commercially available package, which is less advantageous from a weight and handing stand point than dry ingredients. Urine recovery testing used only dry osmotic draw solution ingredients.

Technical Water Treatment Option

Technical waters present another important potential application for the LWC-WRS. Technical waters are roughly defined as vehicle waters that are not normally considered fit for human consumption, and thus are not treated and controlled for this use. Technical water can be water that was drinking water (in a tank) that has become contaminated or has simply been stored past the time for which it can be guaranteed safe. Similarly, if the water source is a water recycle system that has experienced a system upset, the product water may require some limited additional treatment to be considered safe. Finally, some cooling waters and other vehicle waters may be of high quality but untested for biological pathogens but is known to be low in trace toxics. Access to these waters for crew survival may be necessary in an emergency and would be possible through the use of the LWC-WRS.

These waters would probably provide the best productivity option for the LWC-WRS system. As with the seawater option, the commercially available FO membrane element is acceptable as it currently exists for this process application, but will require a flight material upgraded bag. This is a particularly advantageous application because, if the seawater recovery FO bag was stored on a crew vehicle, the same hardware could function on the ISS as a backup/secondary protection during drinking water system upset without any redesign, modification, or repackaging.

The major challenge in addressing the use of the LWC-WRS for technical waters is that the target contaminants are, by the nature of the application, poorly defined. This is generally not a large problem if one accepts the axiom that trace biological pathogens are the primary containment of concern in all of these scenarios. The FO bag will provide treatment for biological pathogens and inorganics to a high enough degree to be considered prophylactic for most conceivable scenarios. However, specific organic treatment targets would need to be defined and tested. For this reason investigation of