Development of a Nutritional Delivery System to Feed Crew in a Pressurized Suit

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ABSTRACT

The contingency scenario for an emergency cabin depressurization event may require crewmembers to subsist in a pressurized suit for up to 144 hours. This scenario requires the capability for safe nutrition delivery through a helmet feed port against a 4 psi pressure differential to enable crewmembers to maintain strength and cognition to perform critical tasks.

Two nutritional delivery prototypes were developed and analyzed for compatibility with the helmet feed port interface and for operational effectiveness against the pressure differential. The bag-in-bag (BiB) prototype, designed to equalize the suit pressure with the beverage pouch and enable a crewmember to drink normally, delivered water successfully to three different subjects in suits pressurized to 4 psi. The Boa restrainer pouch, designed to provide mechanical leverage to overcome the pressure differential, did not operate sufficiently. Guidelines were developed and compiled for contingency beverages that provide macro-nutritional requirements, a minimum one-year shelf life, and compatibility with the delivery hardware.

Evaluation results and food product parameters have the potential to be used to improve future prototype designs and develop complete nutritional beverages for contingency events. These feeding capabilities would have additional use on extended surface mission EVAs, where the current in-suit drinking device may be insufficient.

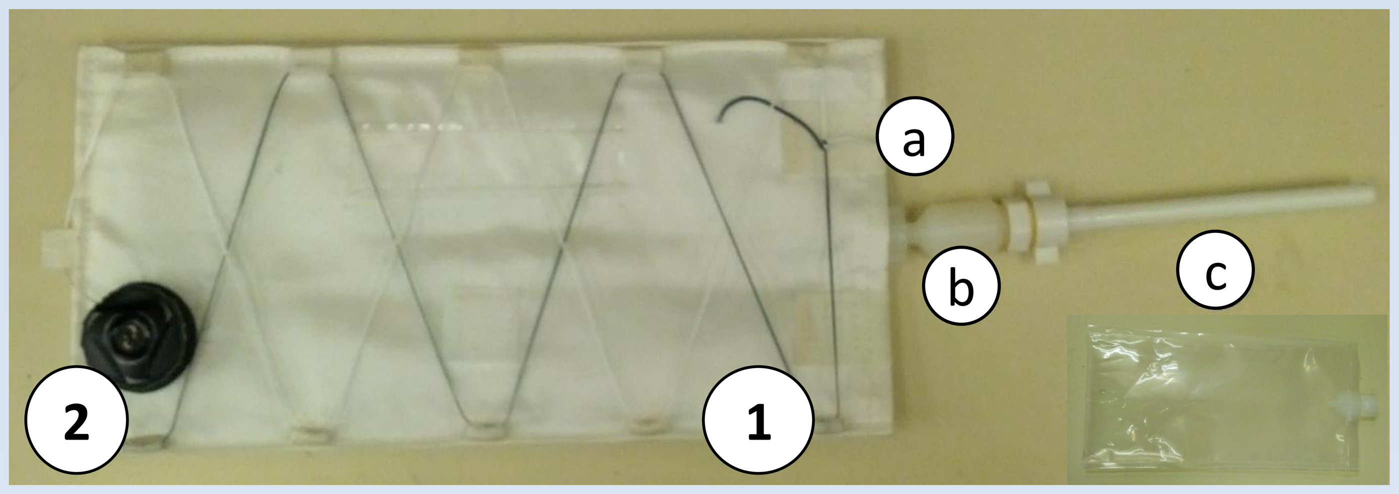
OBJECTIVES

1. Develop and evaluate prototypes for dispensing liquid through a feed port into a pressurized suit.
2. Develop food product parameters that meet nutritional requirements and suit interface criteria.

METHODS – Prototype Development

BOA Restrainer Pouch Prototype

Outer Pouch: (1) 5x11" Nomex® (Dupont, Wilmington, DE), with 10 Nomex® loops along both sides of the pouch, and one loop at the base (Soft Goods Department, Wyle Int. Sci. and Tech. (Houston, TX). Two Lexan stiffeners (SABIC Innovative Plastics, Pittsfield, MA) help maintain shape. (2) Two proprietary Boa cables routed through the loops and connected to a ratchet system (Boa Technology Inc. Denver, CO). Two Velcro straps were sewn onto the top of the outer pouch to enable reuse. Natural Nomex® thread, Size E, was used throughout (American & Efird, Mount Holly, NC).



(a) Septum adapter, modified with hand-tapped 5/16"-18 threads in the top opening where the septum is typically inserted. (b) Pontube adapter, manufactured out of Nylon (Dupont) on a Clausing engine lathe (Kalamazoo, MI). Threads on one end of the pontube adapter were die cut to match those on the inner threads of the US Air Force (USAF) pontube. The opposite end of the pontube adapter was die cut with 5/16"-18 threads to interface with the modified Septum Adapter Assembly. (c) USAF pontube. Inset: Inner Pouch, food grade Combitherm XX230.

Bag-in-Bag (BiB) Prototype

iB prototype complete. Outer Pouch: 5" by 11", Combitherm XX230. Inner Pouch: Combitherm MB110 by Winpak (Winnipeg, Manitoba, Canada). (1) Modified septum adapters connecting inner and outer pouch. (a) Septum Adapter with upper portion removed and opposite end trimmed and die-cut with 10-32 threads, heat sealed into inner pouch 180° relative to a Septum Adapter Assemblies' normal position. (b) Septum Adapter Assembly similarly trimmed and die cut with 10-32 threads. (c) 1/8" polyethylene tubing (Watts, North Andover, MA) hand-tapped on both ends with 10-32 thread. Thread sealant, specifically Loctite Flexible Adhesive (Henkel Corp USA, Scottsdale, AZ) for chamber tests

or FDA approved Masterbond EP21LV (Hackensack, NJ) for suited tests, was used to connect tubing and adapters. (2) Septum adapter assembly sealed into outer pouch for connection of tubing from outer pouch to pontube.

Ingredient	% Mass Composition
DuoCal ®*	45.2%
Whole Milk Powder**	24.11%
Whey Protein Isolate***	12.06%
Sucrose	6.05%
Modified Food Starch +	3.02%
Gum Blend++	0.27%
Total	100%

*DucCal – high calorie nutritional supplement by Nutricia
** 28.5% milk fat solids supplied by Hormel Foods.
*** Optipep 90 supplied by Carbery Food Ingredients
+ Ultrasperse 2000 supplied by Ingredion.
++ Ticaloid Ultrasmooth Powder supplied by TIC Gums.

Basic Instant Beverage Analog

(1) Formulation: The instant beverage analog formulation met macronutrient requirements determined for contingency events. Ingredients were whisked together. Ninety g of powder mix was combined with 175 ml of water for all tests.

(2) Viscosity measurements: Dynamic viscosity was determined for the instant beverage analog and two existing beverage products (US Army Natick Laboratories Dairy Shake (Natick, MA) and Kroger Instant Breakfast (Cincinatti, OH)) using a Brookfield Viscometer (Brookfield Engineering, Middleboro, MA) at 20, 50, and 100 rpm using spindles #5 and #6.

(3) Pouch compatibility / flow rate: The flow rates under normal drinking conditions were determined for a range of viscous fluids (the instant beverage analog, water and glycerol) in prototype pouches against an 8 psi pressure differential in the vacuum chambers. Flow rates (in ml/s) were calculated using the amount of fluid removed from each pouch and the amount of time required for removal.

(4) Rehydration Ratio: Rehydration efficiency was assessed for the instant beverage analog in the BiB pouch by measuring the time required for adequate rehydration with manual kneading.

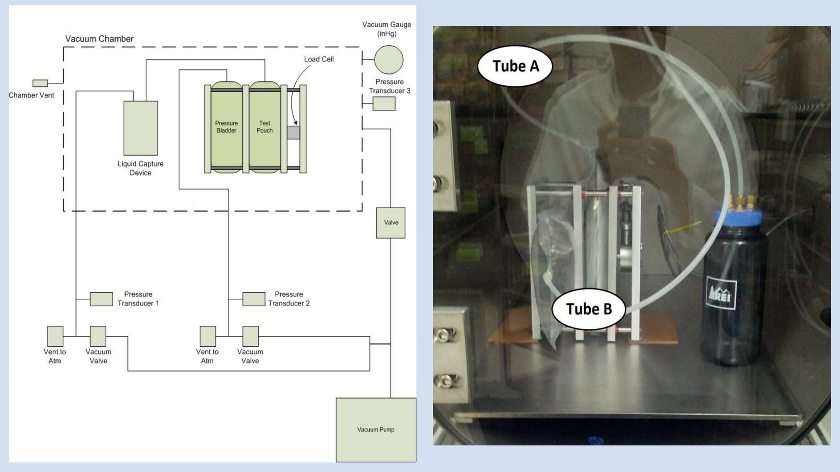
(5) Shelf life Prediction: Isotherm curves of two existing beverage products and the instant beverage analog were generated on the Vapor Sorption Analyzer (Decagon Devices; Pullman, WA). The generated curves were used to predict shelf life of products stored in a BiB package. A computation tool (Decagon Devices) was used to analyze data and predict shelf life based on water uptake and critical water activity.

METHODS – Prototype Testing

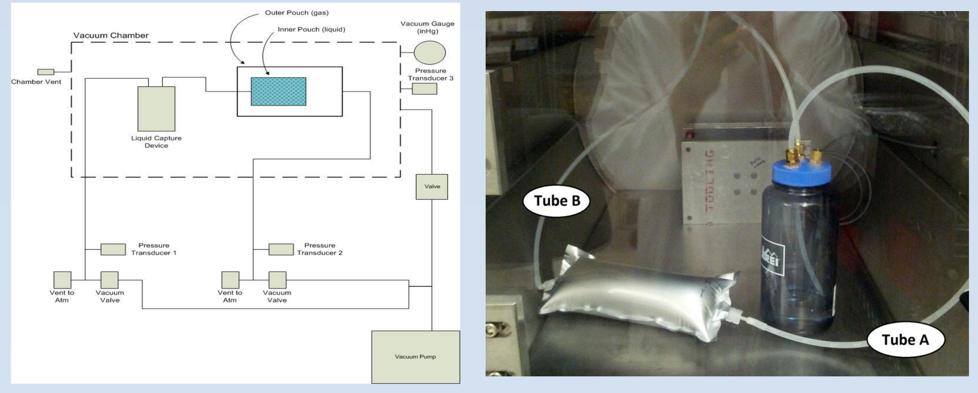
Chamber Tests

A vacuum chamber and data acquisition system were used to measure the pressure required to obtain a range of viscous fluids (water, glycerol, and beverage analog) from each prototype bag against a pressure differential of 8psi. The system was constructed to enable simulation of the required drinking force (Tube A), the pressure differential that needed to be overcome (Tube B, Boa Restrainer Pouch), or pressure equalization into the outer pouch (Tube B, BiB Pouch).

Boa Restrainer Pouch Test Setup



BiB Pouch Test Setup



Suited Tests

BiB pouches were tested by suited subjects, in collaboration with the Crew and Thermal Systems Division.

- The pouch was connected to a pontube, which was inserted into a feed port on the helmet of a test subject in a suit pressurized to 4 psig above atmospheric pressure.
- A test operator aided subjects in drinking from the pontube straw and communicated with them via a two-way radio.
- Three subjects were tested on different days in several different positions.
- Subjects completed a System Usability Scale (SUS) questionnaire (Brooke, 2011).

RESULTS and DISCUSSION

Boa Restrainer Pouch Prototype

- The Boa Restrainer Pouch was designed so that tightening the ratcheting system would empty the beverage pouch. Likewise, it was designed to prevent the suit pressure from backfilling the pouch during drinking, which would inhibit the extraction of the remaining beverage.
- The 8 psi pressure differential caused a 100% failure rate in the inner beverage bags. The failures were instant and in the same location, before external pressure was even applied with the test rig. It is expected that increasing the width of the heat seal at the bottom of the inner boa restrainer pouch may reinforce this seal and improve performance.

BiB Prototype

- The BiB pouch was designed to enable equilibration of pressure around the inner beverage pouch, enabling a crewmember to drink normally.
- Vacuum chamber testing successfully created expected pressure differentials between each packaging layer and the external environment.
- Water was successfully extracted at a rate of 5.74 ml/s.

Suited – BiB Prototype

- All three subjects were able to consume as much water as they liked, drinking normally, once the pontube was inserted and the valve was opened.
- Usability questionnaires indicated that the prototype was easy to drink from but, due to the position of the valve and the lack of shoulder and arm mobility, all subjects felt that it was too difficult to hold up the pouch to the feedport. Only one subject successfully inserted the pontube into the feedport of the helmet. The pouch required additional support from a test operator to insert the pontube into the feedport and support the pouch during drinking.
- Future iterations should include modifications to accommodate restricted arm and shoulder mobility.

Basic Instant Beverage Analog Parameters and Recommendations

- The use of existing beverages is not feasible due to nutrition incompatibility. A custom beverage formula would provide the necessary nutrients without risk of vitamin toxicity. However, existing beverages with target functional properties were used to guide the development of the instant beverage analog.
- Formulation of Beverage Analog: The nutritional content of the prototype met the requirements set by the Nutritional Biochemistry Laboratory. The prototype's nutrient composition is 36.2% fat, 16.2% protein and 47.6% carbohydrates.
- Viscosity measurements of the instant beverage analog were compared to two existing beverages that provided a target viscosity range. The results indicate that the beverage analog fell within the target viscosity range, and was most similar to the Natick Dairy Shake, yielding shear-thinning properties.
- Water, the rehydratable beverage analog, and glycerol were tested in the vacuum chamber to demonstrate the systems capabilities with a range of viscosities. The beverage analog had a similar flow rate to other nutritional rehydratable beverages, but the acceptability of this flow rate during suited testing would have to be confirmed in future subject testing.

Liquid	*Viscosity (cp)*	*Flow Rate (ml/s)*	*Est time to Empty 200 ml (s)*
Water	1	5.74	35
Beverage Analog	780	0.38	526
Glycerol	1500	0.06	3333

- Rehydration ratios were calculated to determine the amount of water required for rehydration and compared to the two existing beverages with target properties. The beverage analog required a similar amount of water per serving to the Natick Dairy Shake.
- Shelf life predictions: Based on the generated vapor sorption isotherms the following shelf life predictions were made for the instant beverages:
  - Natick DairyShake 4 to 10 month shelf life
  - Kroger Instant Breakfast 6 to 15 month shelf life
  - Beverage Analog 10 to 25 months shelf life
- Recommendations for future work include flavor development and micronutrient fortification of the instant beverage analog. It is recommended that the viscosity of the beverage be less than 780 cp at 100 rpm to increase the flow rate when consumed in a contingency event. Sensory acceptability and satiety must be evaluated on the final product. A larger pouch and serving size should be considered as the current configuration would require 7 or 8 servings per day.