# DEVELOPMENT OF A CB RESISTANT DURABLE, FLEXIBLE HYDRATION SYSTEM

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A durable, flexible hydration system resistant to contamination by contact with VX, GD, and HD chemical agents, as well as damage by the decontaminants sodium hypochlorite and DS-2 is being developed for aviator use. Decisions have been made regarding the often conflicting concerns of water potability and protection from chemical agents in compliant polymeric materials. Water potability and health concerns dictate the use of high purity thermoplastic resins with very limited use of lubricants, accelerators, antioxidants, and plasticizers. Flexible chemically resistant applications demand the use of highly crosslinked, permeation resistant, plasticized elastomers or thermosets. By using multilayer laminated and unlaminated polymer composites, as well as closely examining permeation properties, a balance has been reached to meet these conflicting requirements.

## INTRODUCTION

The threat of chemical and biological warfare has accelerated the implementation of protective clothing for aircrew personnel. This protective clothing insulates aircrew personnel and accentuates the need for hydration during long or hot weather missions. Decline in mental performance with lack of proper hydration has been well documented and it is likely that physical performance is also affected[1]. Pilots must have the tools to hydrate in flight to maintain peak performance even in a CBW environment. Therefore, a personal hydration system designed for cockpit use is being developed to meet the hydration need, as well as provide CBW hardened protection of that water source from HD, GD, and VX agents.

The new hydration system was developed to exceed the capabilities of the previous generation two-quart canteen. The previous generation MIL-C-43603B two-quart canteen was designed neither for chemical and biological warfare use nor aviator use. This ethylene-vinyl acetate (EVA) canteen only provided a “disposable” CBW solution for ground forces. The new hydration system, consisting of a flexible water pouch, fill port, drink tube, and connecting hardware has been specifically designed for aviator use with the CBW protective ensemble. It has been designed to integrate with existing CBW aviator hardware and is unobtrusive in a tightly packed cockpit. Construction is modular and will allow adaptation to other military personal hydration configurations.

This paper will first discuss the mechanical design features of this cockpit-compatible hydration system. Next, material selection will be discussed. Finally, performance characteristics of prototype units will be presented. Performance was assessed using various mechanical, thermal, and chemical challenge tests.

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## MECHANICAL DESIGN

The CBW flexible hydration system was designed to integrate with existing aircrew hardware. First, it had to fit inside the AIRSAVE vest. This requirement necessitates flexibility because the water pouch is worn directly against the body, with several components mounted on the outside of the vest. The best way to ensure comfort for the pilot was to make the pouch completely compliant. Second, the pouch was required to connect directly to the M45 protective mask. The M45 mask connects to the M1 cap using an ethylene propylene diene monomer (EPDM) rubber tube and a metal drinking straw. The M1 cap, however, is a large, stiff component that will not fit comfortably inside a vest. Instead, a low profile fill port with a remote connection to the metal straw used with the M1 cap was designed. A comparison of these fittings is shown in Figure 1.

Without the connection for the metal straw provided by the M1 cap, a new location for the drink straw receptacle was required. This fitting was located on the end of a flexible tube that connects to the low-profile spout. The fitting was designed such that it can either be used with the drinkstraw, or in a non-CBW or emergency situation, can be drunken from directly. This situation might occur after a pilot has ejected and is awaiting rescue, but no longer wearing the M45 mask. Figure 2 shows the drink tube fitting connected to the metal drink straw.

Figure 1. M1 cap and spout (l) and prototype low profile spout (r). The low profile spout was designed to lay flat against the body, preventing point pressure in the pilot's ribcage area.

## MATERIALS SELECTION

Aromatic thermoplastic polyurethane was selected as the inner bladder material to come in contact with the water for several reasons. First, it is flexible and tough over a wide temperature range without the use of plasticizers. Ultimate elongations of 500 to 600 percent are typical for urethanes without plasticizers. Other polymers such as PVC require additives to retain flexibility at room temperature, and still become brittle at near freezing temperatures. With regards to mechanical properties, the only other competing materials are elastomers, or rubbers. However, rubbers must be crosslinked by vulcanization using sulfur to obtain useful mechanical properties.

Figure 2. Metal drink straw connected to water pouch fittings. Tethered dust cap also shown. These fittings are sized for ease of placement in the vest, out of the windstream during ejection.

Unreacted sulfur or accelerators, even in very small amounts, imparts a foul taste to water that contacts it for any significant period of time. Additionally, typical rubbers must be chemically glued together, whereas polyurethane is a thermoplastic that readily forms strong thermal welds. Chemical bonding introduces another set of potentially toxic chemicals to drinking water and can be less reliable mechanically. The only problem with thermoplastic urethane is that it has relatively low resistance to permeation by chemical agents. An outer barrier is therefore required.

For the outer protective covering, a multilayer laminate already proven worldwide in industrial chemical protective applications is utilized. This laminate meets performance requirements, including permeation, flammability, and abrasion resistance, of the National Fire Protection Association (NFPA) 1991,1994 edition standard[2]. This proprietary laminate consists of several polymeric layers including a polyamide fiber reinforcement layer for strength, several rubber layers for permeation resistance, and a thermoplastic layer to allow for thermal welding. These materials are shown in Figure 3.

Figure 3. Bladder materials. The clear material is the inner water containing polyurethane, while the outer material is a multilayer laminate barrier.

The requirements for the tubing are not entirely similar to those for the pouch material. First, the tubing must be stiff enough to prevent collapse, but flexible enough to prevent kinking and allow ease of movement. Unfortunately, flexibility is usually related to permeability. Secondly, the tubing must be of a type approved for contact with potable water. It would seem the ideal tubing would consist of a layer of highly resistant fluoropolymer over a soft, flexible potable water formulated polymer. TFE fluoropolymers are inherently stiff and prone to kinking. Multilayer tubing is prone to difficulties with reliably sealing both tubes at the ends. A single layer tubing with the ability to both carry potable water and resist permeation and damage by both CBW agents and decontaminants was required. By choosing a flexible, chemical resistant tubing of a sufficient thickness to keep the permeation rate low, all requirements could be met.

Table 1 shows a listing of the most promising tubing materials. These were tested against dimethyl sulfoxide as an agent simulant. DMSO is polar aprotic solvent and is specified as a chemical agent simulant because it quickly permeates skin, similar to CBW agents, but has relatively low toxicity[3]. It thus provides a safe, worst case testing medium. Testing of tubing materials was performed by placing 20 ml of distilled water into 2 foot long sections of tubing, then immersing the center 12 inches of the tubing in a 50 vol% DMSO, 50 vol% water mix for 72 hours at room temperature and pressure. The water inside the tubes was then collected and tested for DMSO content using a Hewlett-Packard 5890 Series 2 gas chromatograph. Tubes were 1/4”ID by 7/16”OD unless otherwise noted. Table 1 also shows the advantages and disadvantages of each tubing material.

TABLE 1. Tubing material DMSO challenge test results and advantages and disadvantages of each material. Minimum level of detection was 10 ppm. Materials such as silicone rubbers and fluoropolymers were not tested because they were too permeable or too rigid.

| Material | 72 hour water contamination by DMSO, ppm | Advantages | Disadvantages |
|---|---|---|---|
| Tygon lined EPDM (ethylene propylene diene monomer) | <10 | -flexible<br>-highly resistant to permeation | extremely difficult to use with tube fittings |
| EPDM | <10 | -single layer<br>-works well with fittings<br>-very flexible | imparts foul taste to water |
| Food grade Tygon, 3/8"OD | 23<br>(average 0.005 ì g/cm$^2$/min) | -NSF approved-imparts no taste to water<br>-flexible<br>-single layer<br>-works well with fittings | somewhat permeable |
| Food grade Tygon, 1/2"OD | <10 | -same as above, but longer protection<br>-will not kink | -difficult to use with standard fittings (too thick)<br>-permeability |
| polyethylene lined ethyl vinyl acetate | <10 | -tough and strong<br>-cut resistant<br>-low permeability<br>-FDA compliant<br>-seals well over barb fittings without hose clamps | -inflexible<br>-can't use hose clamp valve to shut off flow<br>-possible infiltration between layers |
| fluorinated ethylene propylene lined Tygon | <10 | -flexible<br>-low permeability | -kinks easily<br>-cannot be used with barbed tube fittings or hose clamp valve |

EPDM tubing has the best properties from a mechanical and CBW viewpoint, but the taste of water passing through this tubing is revolting. Personnel would most likely begin suffering the effects of dehydration before they would want to drink water that contacted this tubing or any other rubber materials. It is suspected that residual unreacted sulfur contained in the rubber contaminates water in contact with it. Although not toxic, it takes very little contact time to make the water undrinkable. The Tygon food and beverage tubing, by contrast, was found to add no detectable taste to water. Further testing of a thicker wall 1/4"ID by 7/16"OD food grade Tygon tubing for 96 hours in 50% percent DMSO revealed no contamination of the water inside. It is believed that the claimed exceptionally low porosity of this material keeps permeation rates low without excessive stiffness[4]. From the above data, it was decided that this thickness of food-grade Tygon tubing sufficiently resists permeation and damage by solvents and alkaline solutions, yet provides good flexibility and adds no taste to contacting water.

PERFORMANCE

At this time, the first of two developmental batches of pouch prototypes have been tested. Tests have been classified as mechanical, thermal, and chemical.

The first mechanical test of the water pouch was a drop test. A pouch was dropped from a height of eight feet onto a smooth concrete surface. This test was repeated for each of the 6 orthogonal directions relative to the water pouch as shown in Figure 4. No damage occurred.

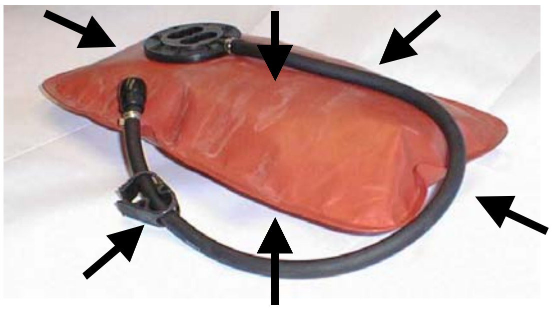

Figure 4. Drop test. The pouch was dropped such that impact occurred from all 6 directions.

The next test was a pressurization test for leakage. A pouch was submerged under 6 inches of water, then pressurized internally to 4.0 psi with air. No leakage occurred. Next, this pouch was placed in a hydraulic load frame as shown in Figure 5. In the configuration shown, a load was applied in displacement control at a rate of 0.5 inches/minute. When held at 1000 lbs. load for 30 seconds, no damage occurred. When the load was increased to 1200 lbs., slow, noncatastrophic separation of the heat sealed area of the outer barrier material occurred in one location. The chemically bonded tape did not separate, however, so no holes actually appeared in the outer layer and no leakage occurred at this location. Approximately 5 ml of water leaked from the spout during this testing. Upon subsequent air pressure testing of the same pouch as described above, a bubble appeared every 5 to 10 seconds at one location on the spout when pressurized to 3.5 psi due to slippage of the pouch material relative to the spout. Subsequent redesign included a reinforcing ring of double thickness polyurethane in the spout region to address this weakness, even though these tests far exceed previous durability expectations.

Figure 5. Crush test. In this configuration, the water pouch withstood a load of 1000 lbs with no damage.

To address the possibility of breakthrough of the inner layer without visible damage to the outer layer, several puncture tests were conducted as shown in Figure 6 using both FTMS 101 M2065 (round tip probe) and ASTM D 4833 (cylinder tip probe) test equipment. To test the pouch material as a system, both layers were placed in the test apparatus in the same configuration as in the pouch. In these tests, puncture of the outer material always occurred first. In fact, the physical limits of the test apparatus were reached before puncture of the urethane material occurred.

Figure 6. Puncture testing of the urethane/polymer laminate system. The puncture probes always broke through the outer layer, but not the inner urethane layer, even after 2 inches of displacement. The inner bladder cannot be punctured without visible damage to the outer material.

Figure 7. Frozen, filled water pouch. No damage occurred.

The final mechanical test was designed to address the possibility of decompression at high altitude during ejection or mechanical failure. The maximum change in pressure that is expected to occur in flight is from filling and sealing at sea level (14.7 psia) to a final cabin altitude after decompression of 40,000 ft (2.7 psia)[3]. To simulate this effect, a pouch was placed in a vacuum chamber and the pressure was reduced from atmospheric to 2.7 psia. Although rapid decompression (<15 seconds) was not difficult to reproduce and did not effect the pouch, explosive decompression (<0.1 seconds) is more difficult and has not yet been simulated. Due to the incompressibility of water and a vapor pressure of only about 0.5 psi at room temperature, the water pouch had to be filled partially with air for this test to be of any consequence. Because the pouch is flexible and there will only be a small quantity of air inside, it is expected that explosive decompression will also have very little effect on the pouch. Decompression effects will be negligible if air is removed from the pouch before sealing.

Thermal tests consisted of soaking and cycling between high and low temperatures. First, a filled pouch was placed in a freezer at 4ºF until frozen solid (approximately 20 hours), as shown in Figure 7. After thawing, the same pouch was placed in an oven at 149ºF for 4 hours to simulate the hottest induced conditions expected, such as within an enclosed vehicle under bright sunlight on a hot day. Next the pouch was placed in a Tenney Environmental Test Chamber and exposed to 100 cycles between -13°F and 203°F at a rate of 2 cycles per hour for 100 hours. No damage occurred in any of these tests.

Although these water pouches have not yet been tested against actual chemical agents and decontaminants, testing of the complete pouches against a DMSO solution does provide a comparable measure of the ability of chemicals with high solvency to penetrate the materials and seals. Pouches were tested by immersing them in a 50% DMSO solution at room temperature for 24 hours. Samples were taken by withdrawing 15 ml aliquots through the drinking tube at exposure periods of 10 minutes, 2 hours, and 24 hours. Of three pouches tested, no DMSO contamination of the water contained inside was detected through 24 hours of exposure. Blind contaminated samples were used to verify the efficacy of the DMSO detection process.

## CONCLUSIONS

A durable, flexible water pouch with the ability to resist contamination by exposure to chemical agents is being developed for aviators. The water pouch was designed to integrate with existing hardware such as the M45 mask and the metal drinkstraw for the M1 cap to form a complete hydration system. Many decisions were made regarding materials of construction to provide strength, flexibility, and resistance to chemical agents. It was found that a multi-layer configuration of thin barriers was appropriate for the main body of the pouch to provide water potability and chemical resistance, whereas a single thick material was appropriate for the drinking tube.

Currently, near production-ready prototypes have been tested. Pressure testing (including depressurization), drop testing, crush testing, thermal cycling, and thermal extremes testing have demonstrated the exceptional durability of the pouch. The water pouch has been characterized for permeation resistance using a chemical agent simulant, dimethyl sulfoxide. The pouch had no detectable permeation of the agent during a 24 hour period.

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