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MILITARY LAND-BASED WATER PURIFICATION AND DISTRIBUTION PROGRAM

James S. Dusenbury, Ph.D.
U.S. Army TARDEC
6501 E. 11 Mile Road
Attn: AMSRD-TAR-D/210
Warren, MI, USA, 48397
dusenbuj@tacom.army.mil

1. Background

Potable water is one of the Army's most basic logistics requirements, particularly in arid environments. It directly affects the health and welfare of the individual soldier as well as the combat readiness of committed forces. During World War I, health problems associated with poor drinking water quality prompted the U.S. Army to address the issue of providing potable drinking water to the field. The principal piece of equipment developed was the "Mobile Water Purification Unit" featuring sand filtration and chlorination. During World War II, it became increasingly apparent that this technology was only partially effective in providing potable and uncontaminated water for drinking, washing, culinary, bathing and laundering purposes. Subsequent to World War II, a complete line of water purification equipment, each designed for use on a different type of source water was developed and fielded. During the 1960's, the Army realized that although these units provided potable water, there was, from a logistical and training standpoint, a distinct need for a single water purification unit capable of purifying raw fresh water, seawater and brackish water. In addition, there was now a need to purify water contaminated with nuclear, biological and chemical (NBC) warfare agents. Consequently, the Army funded research in reverse osmosis technology which resulted in the development and procurement of two systems, the 600 and 3,000 gallon per hour (GPH) reverse osmosis water purification units (ROWPUs). They were fielded in 1981 and 1989 respectively, and are still used today by the Army, Marine Corps, and Air Force.

2. Current Doctrine

Direct support (DS) water sustainment to divisional units is provided by supply point distribution in the present day Army except for light infantry battalions (LIB) where water purification personnel provide distribution to the LIB combat trains, as outlined in FM 10-52 Water Supply in Theaters of Operations [1]. DS support is capable of supplying the divisional water requirements in temperate, tropical, and arctic regions. However the DS support must be augmented by (general support) GS support in arid regions where sufficient water supplies are not available. To provide DS water sustainment water specialists from the supply & service company in the main support battalion (MSB) establish water supply points in each of the brigade support area (BSA) and at up to two locations in the division support area (DSA). When a source of water sufficient to support the purification requirements is available in the BSA water purification and supply points are established in the BSA using Reverse Osmosis Water Purification Units (ROWPU) and water storage assets. When there is no suitable water source available within the BSA a dry water supply point is established in the BSA using the organic water storage assets and purification is conducted at the nearest source. A Water purification point is then set up at the nearest suitable source using ROWPUs to purify the water and transported to the dry water supply point in the BSA using distribution assets, primarily the semi trailer mounted fabric tank (SMFT). All units (less light infantry companies) must use their organic water distribution equipment to pick up water from the approved water point. The unit must dispatch an organic prime mover and a 400-gallon water trailer, 160 gallon pillow tank or 250 collapsible drum to the BSA water point. Due to the limited vehicular mobility of the LIB water distribution is performed by unit distribution. Water is moved forward from the BSA to the LIB by water section forward area water point supply system and transferred to 160 gallon pillow tanks operated by the battalion supply trains. The water will then be taken forward to companies and

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platoons. Units must pick up their water resupply at the battalion distribution points. Unit distribution of water is only provided for LIB. All other units in the Light Infantry Division use supply point distribution.

The equipment in the army's inventory has been developed to support this doctrine and in most cases is well suited for the task. Water purification equipment consists of the 600 gallon per hour ROWPU and 3,000 gallon per hour ROPWU which are currently fielded and the 1500 gallon per hour tactical water purification system and 125 gallon per hour light weight water purifier, which are ready to enter production. These systems can rapidly purify any type of source water including rivers, lakes and oceans and produce quantities to meet the brigade, division, corps and theater of operation requirements. Distribution is accomplished using the Semi-trailer Mounted Fabric Tank (SMFT) or (Forward Area Water Point Supply System) FAWPSS for bulk distribution and 400 gallon water trailer, 250 gallon collapsible drum and 160 gallon pillow tank for retail distribution. A 2000 gallon tank rack that may be transported on a Load Handling System (LHS) or trailer is under development to replace the SMFT to address the significant draw back of not being able to transport the SMFT partially full. The HIPPO and CAMEL are under development to increase the capacity of the unit water trailer from 400 gallons to 900 gallons.

Due to the significant logistics footprint (weight and volume) associated with storing water current doctrine only requires units to maintain water in organic water containers and optional CTA equipment, where water sources to support water purification operations are readily available. For an average unit this means only maintaining enough water to get through that day's operations. Under these conditions units must resupply daily. In arid regions where water sources are extremely limited units must make use of all organic and optional CTA equipment. Combat brigades and divisions, and hospitals are assigned additional water storage and distribution equipment. This ensures that one day of supply is maintained at each echelon level. GS storage and distribution assets are required to maintain adequate supply levels.

3. Review of Existing Equipment

The development of the 600 gph ROWPU was completed in 1979. The system is a highly mobile, versatile and rugged system that may be rapidly deployed and used anywhere on the battle field. The unit uses a combination of physical and chemical treatment processes to produce potable water from any available water source. The ROWPU consists of five major systems: raw water intake, clarification, purification, distribution, and Nuclear, Biological, and Chemical (NBC) decontamination. The raw water intake typically consists of an intake strainer, a raw water pump, and the necessary hoses and valves. In the clarification system the raw water is coagulated by the addition of a cationic polyelectrolyte, then pumped through a multi-media filter followed by a set of 5 micron cartridge filters. The purification system consists of the high pressure pump, eight 6" diameter reverse osmosis elements, and a chlorine injection pump. The chlorine injection pump provides a chlorine residual required by the Army Surgeon General to ensure the water is not recontaminated during storage and distribution operations. The distribution system has 3,000 gallon collapsible fabric storage tanks, a distribution pump, a distribution nozzle, and the necessary hoses and valves. The NBC decontamination system has activated carbon and mixed-bed ion exchange filters to remove NBC contaminants from the purified water. The 600 GPH ROWPU produces up to 12,000 GPD from sources with 35,000 ppm. On waters with lower salinity, the ROWPU will produce more water. The operating day for a ROWPU is 20 hours. The remaining four hours are used for routine cleaning and maintenance. There are three models of 600 GPH ROWPUs: a trailer-mounted unit for the Army, a skid-mounted unit for the Marine Corps and Navy, and a skid-mounted unit wired for use with the bare base electrical system for the Air Force. The 600 GPH ROWPU is powered by a 30 kW generator. All versions can be transported by 5 ton truck, air transported, air-dropped, rail transported, carried on shipboard, or sling-loaded by a cargo helicopter.

The development of the 3000 gph ROWPU was completed in 1987. The system design is similar to the 600 gph ROWPU with the same five major systems: raw water intake, clarification, purification, distribution, and Nuclear, Biological, and Chemical (NBC) decontamination. A major difference is addition of a cyclone separator mounted on the raw water pump to provide initial removal of large suspended particles. The purification subsystem includes twelve 8" diameter RO elements arrayed in two parallel streams with six RO elements in series. The water treatment system and controls are housed in a 8 foot by 8 foot by 20 foot ISO container and mounted on a 40 foot semi-trailer along with a 60 kW generator set and the high pressure pump. The system may be transported by truck, rail, ship, or air.

4. Review of Developmental Equipment

The 1500 gph Tactical Water Purification System (TWPS) will replace the existing 600 GPH ROWPU in the Army and U.S. Marine Corps (USMC) inventory. The design of the 1,500 GPH TWPS uses state-of-the-art technology to increase the potable water output without increasing the size, weight, or deployment features in comparison with the 600 GPH ROWPU, and to improve water production efficiency and flow rates from sources with high salinity contents. The existing 600 GPH ROWPU has insufficient water production and uses outdated pretreatment technology. The existing system is not capable of providing acceptable quantities of potable water from seawater with extremely high total dissolved solids (TDS) levels, such as those encountered during Operation Desert Shield and Desert Storm. Also, it is not capable of providing acceptable quantities of potable water from low temperature (e.g. 32 degrees Fahrenheit) water sources. The 600 ROWPU's pretreatment filters require excessive backwashing and/or replacement when operating on turbid source waters (greater than 20 nephelometric turbidity unit (NTU)). Another consequence of operating the current system on turbid source waters is that the pretreatment system may allow colloidal particles to travel through the filters and enter the Reverse Osmosis (RO) elements. This will typically result in premature cleaning of the RO elements and may possibly cause such significant fouling that the expensive RO elements will need to be replaced.

The 1,500 GPH TWPS is a fully contained mobile water purification system consisting of seven process systems: a raw water system, a microfiltration (MF) system, an RO system, an air system, a chemical injection system, the product distribution system, and a NBC purification system. The system utilizes MF pretreatment to remove suspended solids and bacteria, and high rejection spiral wound RO membranes to produce potable water from fresh and brackish water sources as well as from salt water up to 60,000 mg/l TDS. The TWPS produces a minimum of 1500 GPH of potable water from fresh water sources, as well as a minimum of 1200 GPH from brackish, salt, and nuclear, biological, and chemical (NBC) contaminated water. The TWPS has two configurations, one for the U.S. Army and one for the U.S. Marine Corps. The Army's TWPS is mounted on a flatrack and the USMC TWPS is a skid-mounted unit, but does not include the power source (i.e. generator).

The raw water system pumps raw water from the water source to the TWPS through a floating inlet strainer with an anchor and rope, raw water suction and discharge hoses, a cyclone separator, and a static mixer. The TWPS also has an ocean intake structure system (OISS) which is used for drawing raw water through beach well point intakes for raw water sources with surf or extreme tidal conditions. MF feed water is drawn through dual 600-micron strainers, and then to each of 12 MF modules in parallel. Entering each module, the feed flows around the outside of the fibers and then through the 0.2 micron nominal membrane surface of each fiber and into the hollow core. The filtered feed water flows to the high pressure pumps that discharge to the pump end of the power recovery turbocharger where the pressure is boosted before entering the first of five RO pressure vessels arranged in a series array. Each vessel contains two 8" x 40" spiral thin film composite polyamide RO elements installed with a blanking plug between the permeate tubes. From the last vessel the concentrated feed water, now reject, discharges to the turbine side of the turbocharger where the pressure is converted to energy to run the pump side. A chemical injection system adds calcium hypochlorite to provide a residual of up to 10-mg/l free chlorine prior to discharge to one of two 3,000 gallon product distribution tanks. The NBC filter system is a separate component, to be used when purifying NBC contaminated water, that consists of ion exchange resin and activated carbon.

The Lightweight Water Purifier (LWP) provides the U.S. Army with the capability to produce a safe, reliable supply of potable water to support ground, amphibious, air mobile, and airborne units. The primary mission of the system is to purify water obtained from a broad range of sources, including NBC contaminated sources, to meet requirements for small military units and detachments, Special Operations Forces (SOF), and temporary medical facilities during a large range of military contingency operations to include combat, stability operations, and support operations. The LWP will be primarily transported over land in the rear compartment of the High Mobility Multi-Purpose Wheeled Vehicle (HMMWV) M1097A, and by air inside the C-130 aircraft or an UH-60 helicopter. The LWP produces 125 GPH of potable water from a fresh water source and 75 GPH of water from a seawater source. The LWP is a modular system that consists of the following process systems and modules: raw water feed system, ultrafiltration module, high pressure pump module, RO module, chemical injection/ cleaning module, NBC post-treatment system, product water distribution system, and power source.

The raw water system consists of an electrically powered feed pump, coagulant injection system, and a collapsible fabric tank settling tank. The settling tank is used for the raw water source and allows suspended solids to settle to the bottom of the tank. The settling tank will reduce the solids loading on the ultrafiltration (UF) membranes thereby increasing the time between cleanings. Clarified water from the settling tank is fed to the UF Module by an electric motor driven pump. The UF module is a welded aluminum pipe frame that houses the three 0.1 micron UF membrane cartridges. The HP module houses a diesel engine driven high-pressure plunger pump that pressurizes the feedwater prior to treatment by reverse osmosis. The RO Module contains seven 2.5" diameter RO membranes in Titanium pressure vessels. The chemical injection/cleaning module houses a 20-gallon tank used for batching, mixing, and heating the cleaning solutions for the UF and RO system and to hold fresh product water. There are three, 2.5-gallon tanks for either sodium bisulfite (dechlorinating agent) or coagulant depending on the source water, antiscalant solution for the RO membranes, and a hypochlorite solution for disinfecting the product water. The NBC filter assembly consists of activated carbon to remove chemical warfare agents and ion exchange resin to remove radioactive contaminants. The system is only employed if the presence of NBC agents is suspected. The product water, after chlorination and NBC post treatment (if required) is stored in a 1000 gallon collapsible fabric tank.

5. Future Force Sustainment Concept

Conventional U.S. Army water sustainment doctrine and equipment will have difficulty meeting the challenge of supporting the emerging Future Force sustainment and operational concepts. New material is critical to transform water sustainment so that it will achieve the goals of the Future Force sustainment and operational concepts. Current water sustainment doctrine is based on locating a source of water sufficient for bulk water purification, purifying large quantities of water rapidly, and then distributing the purified water forward via hose systems, vehicles, and finally trailers, pillow tanks, and jerry cans to reach the maneuver companies.

To meet the needs of our nation in the 2015-2020 timeframe, the Army must have a new tactical force—the Unit of Action Combat Brigade. Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) and force sustainment will become even greater multipliers on the battlefield than in legacy and interim force operations. The Army must rethink organizations and doctrine to capitalize on these multipliers. The Army is continually developing more lethal systems, restructuring organizations, and refining doctrine. The Future Force Operational Concept fulfills the Army Vision of fielding combat brigades capable of deploying in 96 hours from the departure of the first unit from a continental United States (CONUS) base. The operational concept for the UA leverages the integration of advanced information and material technologies interconnected by an info-sphere with the employment of tactical combined arms units capable of rapidly deploying from strategic distances and able to fight –on arrival.

Sustainment is generating, maintaining, and regenerating combat power and a corresponding operational tempo. Sustainment operations aim at minimizing the frequency and duration of operational and tactical transitions where momentum is lost. UA units are sustained through pulsed logistics, reducing its footprint. Unit sustainment is provided through mission staging and sustainment replenishment events that are synchronized with the maneuver commander's battle rhythm. Mission staging is an intense, time-sensitive operation which includes all preparations for an upcoming mission:

planning, troop leading, rehearsals, training, reconnaissance and surveillance, reconstitution, tailoring for next mission, information operations, etc. to ensure mission success. Sustainment replenishment is a quick, in-stride, sustainment operation that is designed to maintain the operational tempo. This is similar to a "pit stop" operation. Sustainment replenishment can either be a deliberate or a hasty operation if an opportunity exists or circumstances insist. This replenishment operation provides arm, fuel, fix, medical support and personnel replacements only as required to meet the immediate needs of the maneuver commander. Sustainment pulses are used to minimize the logistical risk associated with non-secure lines of communication and grey space. As a result of the pulse concept units will need to operate with out external resupply for extended periods. The sustainment concept calls for pulses will be 3 days for high intensity operations and 7 days for low intensity operations. Which means to units must operate without external resupply for these lengths of time. Brigade combat team sustains itself for three days of high tempo operations and seven days in smaller-scale contingencies without replenishment from external sources. Soldiers conducting dismounted operations receive sustainment support from their FCS platform (e.g. on-board water generation).

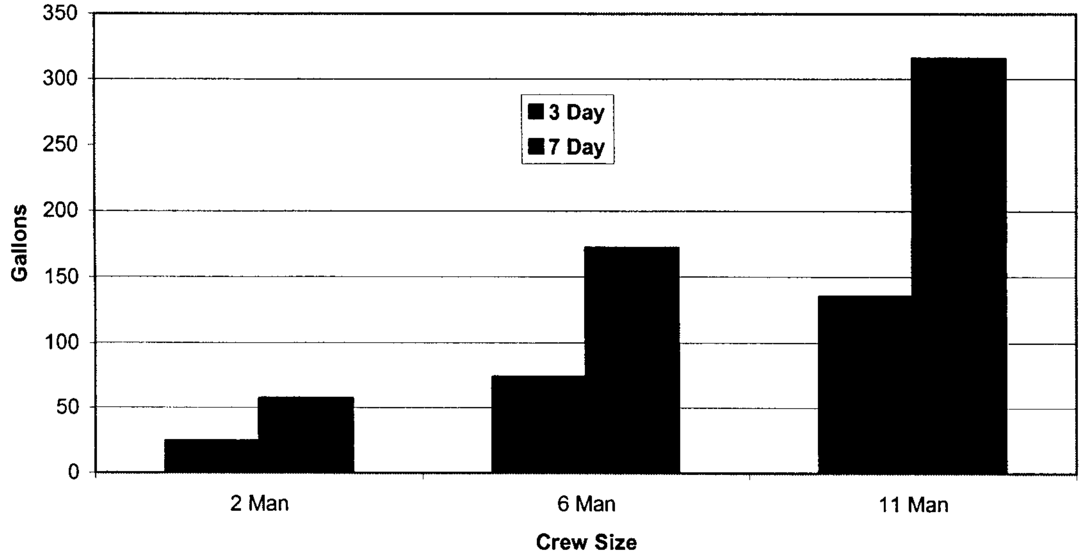
In order to achieve the Future Force desired concept of 3 to 7 days of operation without external resupply or a resupply pulse the Future Combat System (FCS) must have enough water storage to support the organic crew members. This is in contrast to the current doctrine of having just enough water storage for today. The concept calls for 3 days independent operation during high intensity operations and 7 days of independent operation during low intensity operations. However, unlike other classes of supply such as fuel and ammunition, water consumption remains relatively constant regardless of the intensity of the operation. The "Water Consumption Planning Factors Study Report" prepared by the U.S. Army CASCOM in 1999 [2] provides minimum and sustaining water consumption factors related to military personnel in the force structure in hot, temperate, and cold environments (Table 1). The minimum water requirement for drinking is 1.5 gallons per soldier per day in a temperate environment, 2.0 gallons in a cold environment and 3.0 in a hot environment, including both tropical and arid. The universal unit level include factors for personal hygiene, field feeding, heat injury treatment, and vehicle maintenance. The minimum water consumption figures range from 3.26 gallons per soldier per day for a temperate environment to 4.96 in a hot arid environment. The sustaining water consumption factors range from 6.01 gallons per soldier per day in a temperate environment to 7.71 in a hot arid environment. The nominal planning factor the FCS is 4.1 gallons per soldier per day. This provides the flexibility of reducing the daily consumption to 3.0 to achieve an extended operational time frame in emergency situations and doubling the time before resupply is required. Using the nominal water consumption-planning factor the size and weight of the required water storage in the FCS may be calculated for various crew sizes (Figure 1). For an FCS with a crew of 2 the required water storage for 3 days of operation without resupply is 24.6 gallons or 204.2 pounds. The 7 day requirement for the same configuration is 57.4 gallons or 476.4 pounds. For an FCS with a crew of 6 the required water storage for 3 days is 73.8 gallons or 612.5 pounds. The 7 day requirement for the 6 man crew is 172.2 gallons or 1429.3 pounds or almost 3/4 of a ton. For an FCS variant with a 11 man which has 11 organic soldiers it must support the required water storage for 3 days of operation is 135.3 or 1123.0 pounds or over ½ a ton. The 7 day requirement to support 11 soldiers is 315.7 gallons or 2620.3 or over 1 ¼ tons. In all cases the 7 day requirement represents a significant fraction of the overall FCS weight budget. In the cases of the 6 and 11 man crew this will seriously impact the ability to achieve the FCS required capabilities. For the larger crew sizes 6 and 11 soldiers even the 3 day requirement will be a significant portion of the total weight budget and impact the ability to provide all the required capabilities. For the Objective Force to achieve the desired 3 to 7 days of operation without external resupply either each individual FCS will have to dedicate a significant portion of its total weight allotment to water storage or pull a water trailer. The other option for the Future Force to achieve the desired 3 to 7 days of operation without external resupply is for the Unit of Action to include a large number of water trailers that can be rapidly brought forward to each individual FCS for resupply

Table 1 Extract from Potable Water Consumption Planning Guide, Jun 99

CONVENTIONAL THEATER

FUNCTION	HOT				TEMPERATE		COLD	
	TROPICAL		ARID					
	Sustaining	Minimum	Sustaining	Minimum	Sustaining	Minimum	Sustaining	Minimum
Universal Unit Level Consumption	7.51	4.76	7.71	4.96	6.01	3.26	6.51	3.76
Level I and II Medical Treatment	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Central Hygiene, Shower, Laundry (M-85)	8.30	0	8.30	0	8.30	0	8.30	0
Central Hygiene, Shower, Laundry (LADS)	2.05	0	2.05	0	2.05	0	2.05	0
Level III and IV Medical Treatment	1.20	1.20	1.20	1.20	1.20	1.20	1.20	1.20
Mortuary Affairs Operations	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Engineer Operations	1.20	0	1.20	0	1.20	0	1.20	0
Aircraft Maintenance Operations	0.20	0.20	0.20	0.20	0.20	0.20	0.20	0.20
Potable Planning Factor (M-85)	8.75	6.00	18.66	6.41	7.25	4.50	7.75	5.00
Potable Planning Factor (LADS)	8.75	6.00	12.41	6.41	7.25	4.50	7.75	5.00
Nonpotable Planning Factor (M-85)	9.71	0.21	0.00	0.00	9.71	0.21	9.71	0.21
Nonpotable Planning Factor (LADS)	3.46	0.21	0.00	0.00	3.46	0.21	3.46	0.21
10% Loss Factor w/M-85	0.88	0.60	1.87	0.64	0.73	0.45	0.78	0.50
10% Loss Factor w/LADS	0.88	0.60	1.24	0.64	0.73	0.45	0.78	0.50
Total Theater w/M-85	19.34	6.81	20.53	7.05	17.69	5.16	18.24	5.71
Total Theater w/LADS	13.09	6.81	13.65	7.05	11.44	5.16	11.99	5.71

Figure 1 FCS Water Requiements



6. Current Research Efforts

No single technology will be able to meet the challenges of the Future Force, however, technology advances will develop a suite of technologies that may be used collectively to meet the requirement. New technology will provide a more distributed water production capability moving production closer to or right at the point of use. This will significantly reduce the water distribution requirements. This probably will not be able to provide all the water required for the Future Force it will potentially reduce the water distribution requirements by 50 to 66% and enable units to operate for 3 to 7 days without external resupply. This will provide a more flexible, mobile and agile force better adapted to independent operations. While water sustainment of the future force will likely require a suite of technology including legacy and new technology new technology is a must to enable 3 to 7 days without resupply and to reduce the overall logistics footprint. Water is projected to be up to 40 % of the daily sustainment requirement. A 50 to 66% reduction in water sustainment translates into a 20 to 26 % reduction in the amount of supplies which must be delivered and will have even a larger cascading effect. The cascading effect will reduce the amount of water purification and distribution equipment, which must be deployed and the soldiers to operate this equipment. It will reduce the distribution assets and manpower required in the battlespace leading to reductions in the overall water requirement, the logistics requirements to support the soldiers, and the fuel for distribution. New technology will reduce the water storage requirements and the water demand of the combat units. The water produced will augment water storage to provide enough water for a unit to operate for 3 days without resupply.

The goal of the Water Production Technology Research and Development Program is to reduce the sustainment requirement and logistics footprint associated with water production and distribution for the Future and Current Forces. Advances in water sustainment technology are needed to minimize the logistics footprint of the Objective Force Unit of Action. The U.S. Army TARDEC and DARPA are developing revolutionary technologies to produce water anywhere on the battlefield, thereby reducing the logistics footprint by creating distributed water production that reduces the frequency and quantity of resupply. The goal of reducing the water logistics burden will be achieved by pursuing two complementary objectives. The first is the development of water purification technologies that are more energy efficient, lightweight and compact than current state-of-the-art water treatment technologies. The second objective is to generate or recover water on demand from non-traditional sources such as vehicle exhaust and ambient air. These objectives are being pursued under four main thrust areas, Individual Soldier Water Purification, Water from Exhaust, Water from Air, and Next Generation Water Purification Systems. This technology will reduce the logistics footprint by projecting water production forward to the point of use and create a more mobile and flexible water sustainment capability. Integration of potable water generation into combat and tactical vehicles provides units a source of water resupply and is critical for meeting the 3 days without external resupply during periods of high operational tempo and 7 days during periods of low to medium operational tempo without external resupply sustainment concept. Embedded potable water generation would provide the soldiers with the water required to operate without resupply, reduce the logistics footprint for resupply and reduce the need for securing supply routes throughout a noncontiguous battlespace. The capability enhances flexibility of supply operations, and increases available combat power. These technologies will provide military units with a radically more mobile and flexible water production capability, the ability to efficiently purify water in a decentralized manner. The technology will reduce the logistics footprint by creating distributed water purification and production capabilities that may be projecting forward to the point of use reducing the amount of water that needs to be provided by the logistics system. These systems could revolutionize battlefield water sustainment by producing supplemental drinking water wherever the soldier is and thus reducing the quantity and frequency of water resupply.

The Army ROWPU improvement program will consist of investigating three improvements. Improved pre-treatment systems to enhance removal of solids from the raw water and improve the quality of the feedwater to the RO elements to extend the operating life of the elements, reduce cartridge filter replacement, and increase water production. Improved RO element cleaning, preservation procedures, and chemicals to decrease frequency of element replacement, and improve long term storage of elements. New diagnostic techniques and equipment kit for identifying individual elements that are defective and need to be replaced in the field rather than replacing and disposing of all elements at once including those, which are still usable.

The Army advanced reverse osmosis work is developing technology to mitigate the effects of concentration polarization and biological fouling. To reduce biological fouling new membrane chemistries are being created by Separation Systems Technology that are resistant to chlorine. Chlorine will quickly degrade the current membrane materials. Chlorine resistant membranes will enable chlorination to eradicate the microorganisms fouling the membrane. MIOX Corporation is developing a hand held pulsed RO system with advanced spacers. Modeling has shown that pulsing the flow to the membrane will reduce the build up of contaminants at the membrane surface reducing both concentration polarization and fouling. A mechanical pulsing device is being tested to validate the modeling results. Reverse osmosis membranes most commonly come in a spiral wound element. The current spacer material is usually a diamond-patterned mesh that is rolled between layers of membrane. These meshes are not optimized to maximize flow and provide a location for fouling to occur. New spacers that can be directly printed on the membrane are being investigated. These spacers may be created in a wide variety of shapes, sizes, and heights, to improve the flow characteristics reducing concentration polarization and fouling, which are not possible to achieve in a mesh material. The pulsing and new spacer design will reduce the pressure required to operate the system and the frequency with which the system must be cleaned thus reducing operation and maintenance costs. These technologies may be applied to the whole spectrum of Army water purification systems and devices including modular small unit and individual soldier.

The Army is investigating forward osmosis as a technology for individual soldier water purification devices. The device consists of a hydration bag with an FO membrane and a nutrient or "gatorade" type solution used on the product side, which has a higher osmotic potential than the source water. Therefore osmosis occurs across the forward osmosis membrane which is similar to the RO membrane in that it allows the passage of water while rejecting materials down to the ionic level. Forward osmosis has the advantage of being a low pressure process so a system may be made out of lightweight materials and little to no external energy is required for the process since the driving force is provided by the osmotic potential of the product solution. New membrane materials are being developed along with implementation concepts and fabrication techniques to create an individual water purification system. Development of a new hollow-fiber forward osmosis membrane, which will improve production rate through increased surface area, is being performed by Separation Systems Technology.

In the Individual Soldier area MIOX is finalizing the development of the electrolytic disinfection pen (Figure 2). The pen has been demonstrated to be more effective and faster than chlorine and iodine and will purify 150 to 300 liters of water using only salt and water on a single pair of lithium batteries. At normal disinfection concentrations chlorine is ineffective against protozoan oocysts such as cryptosporidium and giardia. At similar concentrations of 2 to 5 ppm mixed oxidants have inactivated 99.9% of cryptosporidium oocysts in less than 10 minutes as well as removing 99.9999% of bacteria. This technology is scaleable from the individual soldier to bulk water purifiers. The pen should be on the shelves in stores in 6 to 12 months and has been accepted as a candidate under the Soldier Enhancement Program to facilitate transition to the soldier. Preliminary testing has been conducted using GD at Dugway Proving Grounds which indicates the MIOX Pen will be effective at destroying certain chemical warfare agents. A large-scale MIOX system has been designed, installed and is undergoing testing on the 3,000 gallon per hour ROWPU. Mesosytems Technology and Mountain Safety Research have been developing an integrated individual soldier water purification, storage and hydration system. The system will include an NBC resistant bladder, filtration, a MIOX disinfection cap, forward osmosis (FO), and an adsorbent. The team has demonstrated an NBC resistant bladder that has been provided to the Marine Corp for field demonstration.

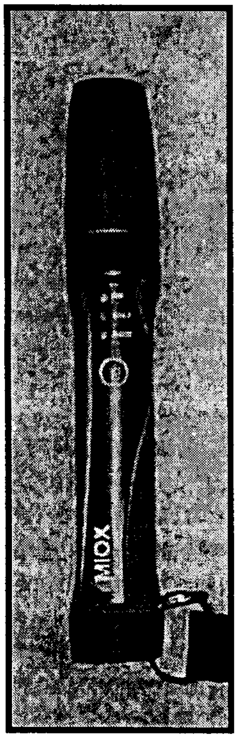


Figure 2 MIOX Disinfection Pen

Biosource Incorporated is developing a new water purification technology based on the concept of capacitive deionization (Figure 3). This concept will be applied to a flow through capacitor, which charges high surface area electrodes to electrostatically remove ions from solution. This technology will be able to produce potable water from any type of source water including seawater. The technology is theoretically more thermodynamically favorable than traditional methods for the purification of water. However, due to materials limitations this technology has not been feasible for seawater purification in the past. Recent material developments by the Biosource Team in carbon technology have provided new materials that enable the development of integrated carbon electrodes with a high electrical conductivity and may be fabricated in a manner to maximize the surface area to pore volume ratio. The fundamental understanding of the critical parameters for capacitive deionization coupled with the developments in carbon technology and a new

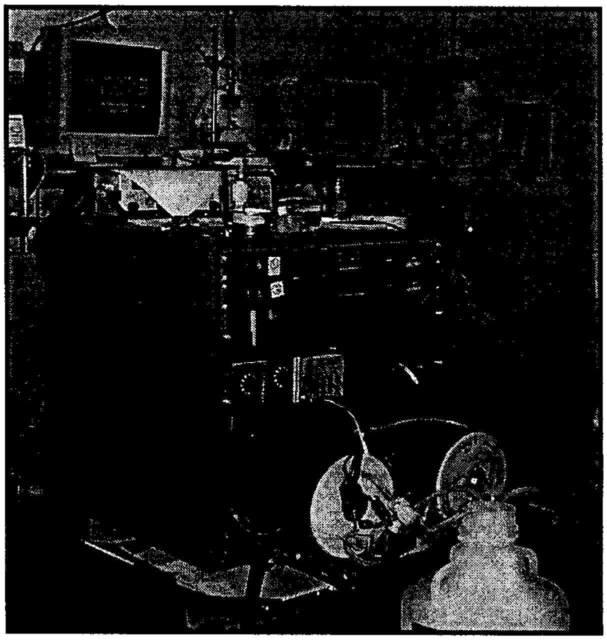


Figure 3 Biosource Capacitive Deionization

charge barrier layer were critical breakthroughs for the development of a prototype that has demonstrated the ability to purify seawater. The FTC has also demonstrated a strong potential for use in the purification of exhaust condensate due to its ability to remove ionic species, raise pH, and the good chemical stability of wetted components. The offeror has demonstrated an innovative energy management and recovery techniques based on the fact that the capacitor is essentially an energy storage device which has a finite adsorption capacity. Therefore, the energy within the capacitor must be periodically discharged to regenerate the adsorption capacity. This energy may be shuttled to a second capacitor to recover the energy. The theoretical maximum for simple energy transfer is 25%, however, the team has developed a novel energy transfer concept that has been able of 60%. The flow through capacitor may enable the development of small unit modular water purification system, vehicle embedded systems and reduce the size weight and operating cost of larger systems.

One of the most promising concepts for producing water from non-traditional sources under development is the recovery of water from internal combustion engine exhaust. LexCarb LLC demonstrated that the water in the exhaust could be collected and purified to drinking water standards, which led to further work to understand the fundamental concepts and apply them to the development of an optimized system. The primary combustion products of diesel fuel are water and carbon dioxide:

$$C_{12}H_{22} + 17.5\ O_2 \rightarrow 11\ H_2O + 12\ CO_2$$

Theoretically, one (1) gallon of diesel fuel produces approximately one (1) gallon of water. In order to recover potable water from engine emissions the water must be condensed from the exhaust gas and then purified. The condensate contains oxides of nitrogen and sulfur from the combustion process that make the water very acidic, as well as, soot particles, organic compounds from incomplete combustion, unburned hydrocarbons, metals, and contaminants from fuels, oils, and corrosion.

To recover water the exhaust gas must be cooled below its dew point, thus initiating condensation. The quantity of water collected is a function of the volume of air treated and the difference between the concentration of water in the exhaust gas and in the cooled saturated exhaust exiting the system. The temperature to which the exhaust gas must be cooled was calculated for recovery efficiencies of 50 to 70%, with recovery defined as gallons of water produced per gallon of fuel consumed. A heat exchanger was designed based on the calculations and preliminary measurements of temperature and flow of the exhaust gas. The cooling energy that must be provided is the sensible heat to cool the exhaust gas from the inlet to desired temperature plus the latent heat of condensation of the water collected. The energy required was determined based on the coefficient of performance of the chiller and the efficiency of the heat exchanger. Trade-off studies were conducted on system size and energy requirements and the optimum recovery was determined to be in the range of 50 to 70%. Test results using the original prototype led a 35% smaller system that consistently recovered 50 to 60% of the theoretically available water.

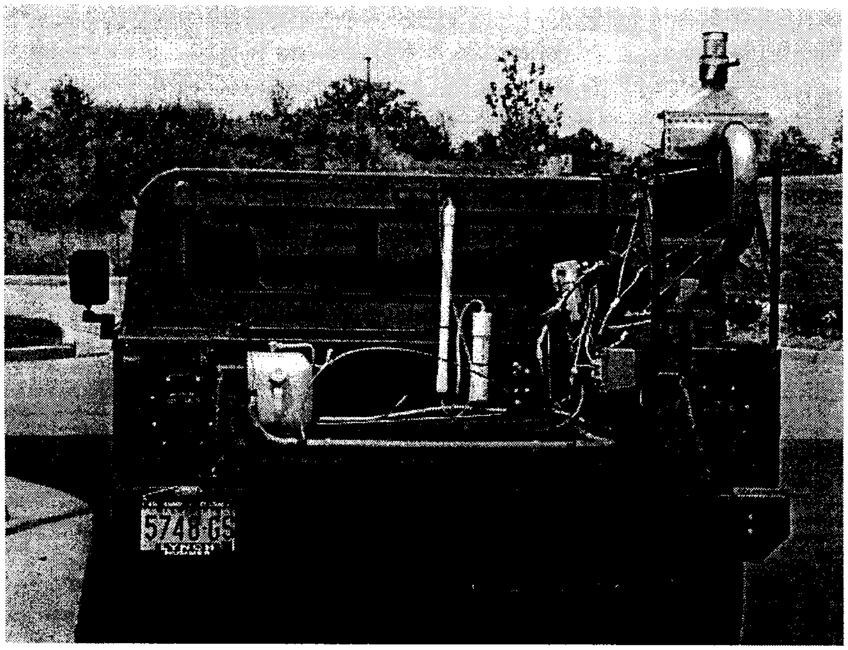


Figure 4 On-Board Water Recovery Unit

Water quality analysis identified soot particles, polar and non-polar organics, and metals in the exhaust condensate. The total organic carbon (TOC) varied from 60 to 360 ppm depending on condensate collection conditions. The primary factors affecting TOC concentration were exhaust system temperature, water yield, engine load, and catalytic converter age. Inorganic contaminants identified included aluminum, zinc, boron, phosphorus and iron. The initial treatment train consisted of filtration, activated carbon fiber monolith (ACF), and ion exchange resin. The filtration step was effective in removing soot particles (initial concentration typically 20 to 100 ppm) and improved condensate appearance from a black liquid to a clear brownish-yellow. The ACF removed small non-polar organics, but was unable to remove larger organics or polar organics and consequently was only able to reduce the TOC by 40 to 50%. The ion exchange material was effective in removing all inorganics except boron. The ion exchange material also had a capacity to remove polar organics reduce TOC. These initial results were used to optimize the water purification process. A wood-based granular activated carbon (GAC) was selected to remove large organics and polar organics resulting in TOC concentrations of 0.1 to 0.3 ppm. A mixed ion exchange resin was formulated to enhance boron removal. The final water treatment was effective in removing all regulated contaminants below drinking water standards. This technology will reduce the logistics footprint by projecting water production forward to the point of use and create a more mobile and flexible water sustainment capability. The technology may enable FCS and units to operate for 3 to 7 days without external resupply of water.

Atmospheric humidity is the most widely and evenly distributed source of water on earth. However, water vapor is always a dilute component of air and in extreme hot, dry environments is only about 1% of the air volume. The mass of water available for recovery from the atmosphere is sufficient to support the soldier even in these hot dry environments, but due to the low concentration the process either requires large quantities of energy to remove the water by condensation or large volumes of adsorbents to concentrate the water vapor coupled with energy requirements that are still quite significant. Approximately 630 watt hours are required to condense a single liter of water and in the hot dry environment this may be only 10% of the total energy requirement if a sufficient quantity of air to produce 1 liter of water must first be cooled to the dew point, from roughly 120 degrees F to 20 degrees F. Unfortunately, conventional methods of collecting this water are too large and energy intensive applicable to battlefield requirements. A system to produce water from air built using current technology and concepts would be over 35 times larger and use 40 times as much energy as conventional Army water purification equipment. In order to have military utility water from air systems must obviously be brought more in line with current water purification equipment.

Promising technologies under development by the Army and DARPA such as, humidity concentration using zeolite and chemically surface modified activated carbon combined with innovative low energy condensation concepts, may make battlefield water generators a reality. In order to reduce the size and energy requirements of water generation systems, cooling based systems must be consistently fed a high humidity source air or new condensation concepts need to be developed using alternatives to cooling. The humidity concentrator collects water from the source air as it flows through the channels of the concentrator. Once a channel has collected all the water it can hold the flow is reversed. This removes the water from the channel and creates a highly humidified product stream. The key to the humidity concentrator is a chemically surface-modified activated carbon that adsorbs the water in the channels. During the project's proof-of-concept phase funded by DARPA, Nanopore Inc., and Mesosystems Technology demonstrated a chemically surface modified activated carbon that could adsorb more water than traditional adsorbents. Of equal importance the team was able to show that the water could be removed from the carbon with less energy than required for traditional adsorbents. This device may be coupled with any device that creates water from air to enhance the system's performance and create a compact, energy efficient system. Another project will be an adsorbent based system that will focus on enhancing performance through the development of more efficient lighter weight adsorbents coupled with innovative condensation approaches. Other approaches supported by DARPA and TARDEC will investigate new ways to condense water based on facilitated membrane transport, variable surface energy materials, and electrostrictive polymers coupled with extremely high coefficient of performance cooling cycles. Under the facilitated membrane project membranes will be developed that act in a manner similar to biological membranes which can pump molecules across the membrane against a concentration gradient. Materials with an affinity for water can be embedded in these membranes to enhance the transport across the membrane and reduce the power requirements. In the variable surface energy project membranes are under development in which water affinity through a pore can be induced to change. In the case of the variable surface energy materials the hydrophobicity/ hydrophilicity can be varied using electric potential. A material can be made to be water loving (hydrophilic) as the source air is fed across the membrane. After the membrane is saturated with water the membrane can be converted to a water hating surface (hydrophobic) by an electric potential causing the water to bead up.

Water from air technology has the potential to enable the development of small modular water purification devices including stand alone water generators for the individual soldier, small units, and subsystems embedded in combat systems or closed-loop water recovery for combat systems. The technologies described above may reduce the size by 5 to 15 times and reduce the power requirements by 2 to 5 times. This power requirement would logistics footprint by 4 to 10 times since each gallon of fuel consumed would produce 4 to 10 gallons of water at these reduced power requirements.

7. Summary and Conclusion

Potable water is one of the most basic logistic requirements for ground based military forces, particularly in arid environments. Water directly affects the health and welfare of the individual soldier as well as the combat readiness of deployed forces. The core technology in the Army and Marine Corp fielded tactical water purification units is reverse osmosis. While the current systems have provided the Army with the capability to purify any source water with sufficient quality and quantities to support deployed troops, both near and mid term improvements are needed to support the water sustainment concept and transformation to a lighter, more mobile and deployable force. Near term improvements are needed in membrane technology and systems to reduce the size and weight of the systems, reduce power, improve resistance to fouling, and improve rejection of potential chemical threat agents. The U.S. Army, Office of Naval Research, and Defense Research Project Agency (DARPA) are conducting collaborative research efforts to develop new membranes, new pretreatment technology, and new membrane system concepts to address the limitations of current technology for military water purification applications. Water distribution is projected to be 30 to 40% of the daily sustainment requirement for a unit of action in a future force using current technology. The goal of mid term research being conducted the U.S. Army and DARPA is to reduce the sustainment requirement and logistics footprint associated with water production and distribution. The goal of reducing the water logistics burden will be achieved by pursuing two complementary objectives. The first is to develop advanced water purification technologies that are more energy efficient, lightweight, and compact than current state-of-the-art water treatment technologies, providing the core technology for the next generation of water purification systems. The second objective is to generate or recover water on demand from alternative sources such as, vehicle exhaust and ambient air, to produce water when no traditional source (river, lake, or ocean) is available providing the core technology for new water generation systems. Two of the most promising concepts under development are water recovery from combustion engine exhaust and water generation from air. In response to changing missions and priorities, the Army is transforming into a lighter, flexible, more responsive force and its ability to purify water must transform as well. Technology to enhance fielded purification systems will provide safe drinking water to all US forces and while improving deployability and reducing sustainment requirements. Future technologies being developed will take things a step further by providing military units with a radically more mobile and flexible water production capability. These technologies will reduce the logistics footprint by projecting water purification and production capabilities forward to the point of use, greatly reducing the amount of water that needs to be provided by the logistics system.

8. References

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