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THE ARMY WATER SUPPLY PROGRAM

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Executive Summary

This paper has two goals: (1) describe current Army efforts to improve the capability and sustainability of its reverse osmosis (RO) based water purification equipment and (2) discuss the ongoing efforts being made under the Water Purification Technology - Science and Technology Objective (STO) to reduce the water distribution requirements of the Legacy and Objective Force.

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 seriously attempt to provide 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 GPH ROWPUs. They were fielded in 1981 and 1989 respectively, and are still used today by the Army, Marine Corps, and Air Force.

Although the currently fielded systems provide excellent quality water, the transition to a smaller, lighter, more mobile force, per the Army Chief of Staff, changes the requirements for military drinking water equipment. The Army in the 21st Century will be involved in operations that require rapidly deployed forces projected from the Continental United States (CONUS) or forward-deployed locations with extended lines of communications on non-linear battlefields. To meet this need, water purification equipment must become smaller, lighter and more mobile as well. Logistic support requirements for this equipment must shrink as well. This change in mission has resulted in the development of two new water purification systems, the 1500 Gallon Per Hour Tactical Water Purification System (TWPS) and the Lightweight Water Purifier (LWP).

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Looking even further into the future, the Army must begin to take advantage of non-traditional water sources to further reduce the logistic, storage and transportation burden associated with providing water on the battlefield. Without advances in water sustainment technology, water distribution is projected to account for 30% by weight of the Unit of Action daily sustainment requirement. Under the Water Purification Technology - STO, U.S. Army TARDEC and DARPA are developing a range of revolutionary technologies for water recovery and generation. Two of the most promising developmental concepts are water recovery from engine exhaust and water generation from air.

1500 Gallon Per Hour Tactical Water Purification System (TWPS)

OPERATIONAL MISSION. The U.S. Army requires the ability to produce a safe, reliable supply of potable water to support ground, amphibious, air mobile and airborne units during combat operations and stability and support operations (SASO). The TWPS will replace the existing 600 GPH ROWPU in the Army and U.S. Marine Corps (USMC) inventory.

The existing 600 GPH ROWPU has insufficient water production and uses outdated pretreatment technology. The 600 GPH ROWPU will not operate adequately in freezing temperatures (below 32°F), and has limited mobility due to its excessive weight. 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 frequent backwashing and/or replacement when operating on turbid source waters (greater than 20 nephelometric turbidity unit (NTU)). On such turbid water sources, the amount of mission time spent producing water decreases due to increased time required for additional preventive maintenance checks and services (PMCS) (backwash or replace filters). Another consequence of operating the current system on turbid source waters is that the pretreatment system may allow excessive amounts of 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 Army version of the TWPS will be used to meet water support requirements within the division area. This requirement supports the Army's combat, combat support, combat service support, and SASO missions. The USMC will use the system to support Marine Air-Ground Task Forces (MAGTF) in both amphibious and expeditionary environments to purify water. This system fills the mission need by providing a tactical water purification system that is mobile and capable of purifying a broad range of water sources anywhere in the world.

OPERATIONAL CONCEPT. The TWPS concept of operation is to produce water as far forward on the battlefield as possible using a flexible and mobile treatment system during war and peacetime scenarios. The system will be used to support existing doctrine for supply point distribution, as well as emerging concepts for unit distribution of potable water. The governing parameters are the number of personnel for which support is required, and the climatic conditions in which the system will be employed. Employment of the TWPS will reduce operator manpower at each water point by 25 percent and will provide substantial reductions in logistical support since each TWPS replaces two 600 GPH ROWPUs.

TWPS EMPLOYMENT. Employment of the TWPS will be governed by mission, enemy, time and training-terrain considerations since water sources must be identified and approved as an operation develops. The TWPS system is designed for quick relocation to support existing combat doctrine. The system will be issued to support water units, prepositioned afloat for operational projects, and stored for extended periods in war reserve stocks. Designated as an enhancement to the IBCT, the TWPS will provide a means for producing a safe, reliable supply of potable water to support the interim, legacy, and objective forces.

The TWPS will be employed throughout the division as a direct support asset during the wartime mission. Existing Army doctrine projects up to five separate water production locations in the division area. The main support battalion will employ the TWPS throughout the division support area at locations where acceptable water supplies exist. The TWPS will produce water that will be distributed at the point of production, line-hauled to forward supply points, and/or line-hauled to major consumers (e.g., hospitals). Additionally, the TWPS will be used to support SASO (e.g., disaster relief, humanitarian assistance, peacekeeping missions, etc.) and training missions.

System Description. 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 to meet water support requirements. Specific chemical and nuclear contaminants will require the TWPS production be reduced to less than 1200 GPH. The TWPS has two configurations, one for the U.S. Army and one for the U.S. Marine Corps.

The Army's TWPS (A-TWPS) is mounted on a flatrack and is transportable by the Heavy Extended Mobility Tactical Truck (HEMTT) Load Handling System (LHS), Palletized Loading System (PLS) trucks and PLS trailers. The system includes the basic TWPS skid, all Basic Issue Items (BII), a military 60 kilowatt (kW) Tactical Quiet Generator (TQG), a 15,000 gallon water storage and distribution system, and all extended capability, which consists of five modules: (a) Ocean Intake Structure System, (b) Supplemental Cleaning, Waste and Storage, (c) Cold Weather, and (d) Nuclear Biological and Chemical (NBC) Treatment and (e) NBC Survivability.

The USMC TWPS (MC-TWPS) is a skid-mounted unit transportable by the Medium Tactical Vehicle Replacement (MTVR) truck (MK 23, MK 25) or by a 5-ton forklift.

The system includes the basic TWPS skid, 6,000-gallon water storage capability, and all BII, but does not include the power source (i.e. generator) or the extended capability modules. The five modules will be purchased and deployed separately as required by their mission.

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 1,500 GPH TWPS has been designed for a 20 year life, with a mean time between failure of 180 hours.

The 1,500 GPH TWPS is a fully contained mobile water purification system consisting of the following process systems:

1. Raw water system
2. Microfiltration (MF) system
3. RO system
4. Air system
5. Chemical injection system
6. Product distribution system
7. NBC purification system

Power is supplied by a government furnished 60 kW Tactical Quiet Generator set. Control is provided through a Program Logic Controller (PLC) with individual Light Emitting Diodes (LED) displays, switches and push buttons. 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 MF automatically backwashes on a preset 15 minute operating time interval. System flow rates and tank capacities are designed to maintain potable water production while the backwash is in process. A flow diagram of the TWPS is contained in Figure 1.

Raw Water System

The raw water system pumps raw water from the water source to the TWPS. The main components of the raw water system are the floating inlet strainer with an anchor and rope, raw water suction and discharge hoses, a diesel engine-driven pump, an electric motor-driven pump, a cyclone separator, a static mixer, and various adapters that connect the hoses to the components of the raw water system. When drawing salt water from a beach location, the second pump discharges through a hydro-cyclone to remove sand.

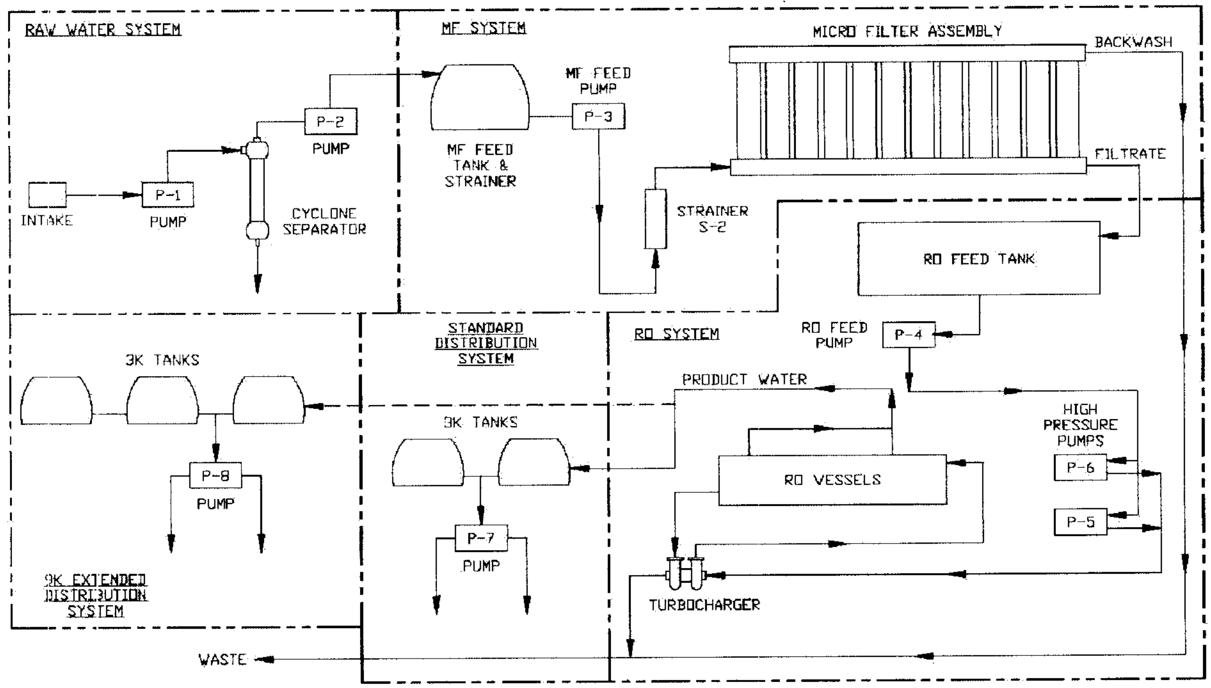


Figure 1. TWPS Flow Diagram.

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. The OISS consists of four well points with risers connected to a header by hoses. The well points are slotted and screened to keep the beach sand out of the well points and risers. The well points and risers are jetted into the sand using one of the raw water pumps to draw water from the source and discharge it through a riser and wellpoint. Once the riser/wellpoint assemblies are installed, the pumps are set up as usual with the suction attached to the header end of the OISS. Water is drawn up through the well points and pumped through the raw water system.

Within the main TWPS skid, the raw water flows through a manual flow control station and then back out through a skid connection and hose to the MF Feed Tank. When operating on chlorinated municipal water, a sodium metabisulfite chemical injection system is used to neutralize the free chlorine.

MF System

MF feed water is drawn from the MF Feed Tank by the MF Feed Pump, which is deployed, on the ground near the tank. The feed discharges through hose to the TWPS skid MF feed connection, through dual 600-micron strainers, and then to the MF assembly upper and lower feed connections. The feed flows through upper and lower internal channels to each of 12 MF modules in parallel. Each module contains a bundle (lumen) of hollow fibers. Entering each module, the feed flows around the outside of the fibers and then through the micro-porous membrane surface of each fiber and into the hollow core. The small, 0.2 micron nominal, pores filter out almost all of the suspended solids and bacteria. The filtered feed water is discharged through a flow control valve to the RO Feed Tank. During MF backwash, this tank provides the reserve capacity to sustain operation of the RO section.

RO System

From the tank, the filtered feed flows to the RO feed pump and is discharged to the High Pressure Pumps. A chemical injection system adds an antiscalant (Hypersperse AF 150 UL) to avoid scale formation in the RO elements as the water is concentrated. The high pressure pumps are positive displacement direct driven pumps with pistons driven by a hydrodynamic swash plate.

The High Pressure Pumps 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. The RO permeate is discharged from each end of each vessel to allow direct measurement of the flow and purity of water delivered by each of the 10 RO elements. From the last vessel, the concentrated feed water discharges to the turbine side of the Turbocharger where the pressure is converted to energy to run the pump side. The operating pressure is adjusted with a main and an auxiliary pressure valve, which are used to bypass the Turbocharger. The maximum pressure at the High Pressure Pump discharge is approximately 900 pounds per square inch gauge (psig). The maximum pressure at the Turbocharger outlet is 1,200 psig. The Waste Out hose directs the RO reject and the MF backwash water back to the water source away from the raw water intake.

Air System

An air system is provided to supply the air necessary to backwash the MF and to operate the automatic valves and control valves. A high pressure compressor supplies air to a receiver tank to 1,300 psig shut-off. Air at 90 psig is supplied for MF backwash and automatic valve operation. Air at 15 psig is supplied for MF drain and purge steps in the backwash cycle and other instrument uses.

Chemical Injection System

The six chemical compounds used by TWPS in the water purification process are listed below.

1. Calcium Hypochlorite – Supplies chlorine to the process water after RO treatment
2. Sodium Metabisulfite – Dechlorinates chlorinated water from a municipal water source
3. Hypersperse AF 150 UL (acid) – Is an antiscalant for the RO membranes
4. Bioclean 442 – Used for MF and RO membrane cleaning, and also as a RO membrane preservative
5. Caustic Soda (Sodium Hydroxide) – Used for standard MF membrane cleaning
6. IPA 411 – Used in standard MF membrane cleaning, and in unusual RO membrane cleaning

Product Distribution System

The permeate from each element is collected in a header and piped to the skid potable water outlet connection. Immediately before the outlet, a chemical injection system adds calcium hypochlorite to provide a residual of up to 10-mg/l free chlorine. A hose discharges to one of the two 3,000 gallon product distribution tanks. The distribution pump draws water from both tanks and provides up to 125 GPM total through two distribution nozzles.

NBC Purification System

The NBC filter system is a separate component to be used when purifying NBC contaminated water. When the system is deployed, a tripod is erected and the filter tank is suspended from the tripod followed by the installation of the collector in the tank bottom. The filter media and the inlet distribution pipe are added and the anti-siphon pipe is connected. When in operation, the water passes from the inlet distribution pipe, uniformly through the media, to the bottom collector pipe. The NBC filter media consists of approximately 180 pounds of ion exchange resin and 186 pounds of activated carbon. After 100 hours of NBC mission operations, the contaminated filter media and flexible tank must be replaced.

Lightweight Water Purifier (LWP)

OPERATIONAL MISSION. 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 utilizes the latest, state-of-the-art, reverse osmosis technology to produce 125 GPH of potable water from a fresh water source and 75 GPH of water from a seawater source. The LWP will be modular and each module will be portable by 4 personnel, either by hand or with mechanical assistance (hand truck), and be containerized in a TRICON.

OPERATIONAL CONCEPT. The operational and support concept is to produce water as far forward as possible using a flexible and highly mobile treatment system during war and peacetime scenarios. The LWP will be issued to support units, prepositioned afloat for operational projects, and stored for extended periods in war reserve stocks. Because of its light weight and transportability, the LWP can be used during reconnaissance operations to produce potable water for forces throughout the theater of operation. The LWP will serve as the prime water purification source for small units that cannot be resupplied with water by standard supply point distribution. Medical task forces and Special Forces groups will use the LWP when operating independently at remotes location during low intensity conflicts and when feasible during initial and / or early entry to an underdeveloped theater of operations.

The LWP is not intended to replace the existing support structure, but rather to supplement it in situations where it is not feasible or practical to employ traditional water purification and distribution methods. Shortfalls of the existing systems are identified in the paragraphs below.

Aerial re-supply is expensive and wastes valuable transport cargo space. The current means of providing water to remote forces is to conduct frequent aerial re-supply with bottled or tactically packaged water. In many instances, potable water shipped by sea becomes non-potable due to long storage time and inappropriate storage conditions.

Existing water purification equipment is too large and not easily transportable. Current requirements and new emerging concepts for modular water support companies require small water purification equipment to enhance water support flexibility required on the battlefield of the future. The existing 600 GPH ROWPU and 3000 GPH ROWPU and the TWPS, under development, are too large and heavy for modular support to remote/undeveloped sites, small military units, SOF, and some Army Medical Detachments (AMEDD) units during independent and remote deployments.

Bottled water obtained from the Continental United States (CONUS)/Outside Continental United States (OCONUS) suppliers is not as safe, or reliable as ROWPU produced water. Medical intelligence estimates suggest that host nation bottled water suppliers in many areas of the world have severe source water quality problems due to improper disposal of hazardous chemicals that are not removed by conventional water treatment processes. Advanced water treatment processes required to remove these contaminants are not generally used during host nation water purification.

LWP EMPLOYMENT. The LWP will be employed throughout the range of highly developed, densely populated urban areas to isolated rural areas in undeveloped countries. Generally, deployment of the LWP shall be governed by Mission, Enemy, Time, Troops and Terrain (METT-T) considerations since water sources must be identified and approved in accordance with existing doctrinal requirements as an operation develops. The LWP is designed for quick relocation to support existing combat doctrine. The LWP will not be operated in an NBC contaminated environment; however, the system may be used to purify NBC contaminated water sources and must be NBC survivable. The LWP will be used when logistical constraints prohibit use of the 1,500 GPH TWPS or the 3,000 GPH ROWPU and will be compatible with ground, amphibious, air mobile, and airborne units. The LWP will be issued to SOF, medical and water support units. The LWP may also be prepositioned afloat for operational projects, and stored for extended periods in war reserve stocks.

System Description. The LWP has been designed to meet the following major system requirements:

1. Produce potable water that meets the field drinking water standards identified in the Tri-Service Field Water Quality Standards, North Atlantic Treaty Organization (NATO) Standardization Agreement (STANAG) 2136, and Quadripartite Standardization Agreement (QSTAG) 245 from all surface and ground sources of fresh, brackish, and sea water, including NBC-contaminated water.
2. Produce a minimum flow of at least 75 GPH from a water source with 45,000 mg/L Total Dissolved Solids (TDS) and 125 GPH from a fresh water source with 1,000 mg/L TDS.
3. Total system weight must not exceed 1,500 pounds. This includes the weight of the power generation equipment used to operate the LWP, all Basic Issue Items (BII) plus any supplies and/or consumables required to support 140 hours of LWP operation.
4. The LWP shall fit into the rear cargo bed of a M1097A truck cargo, HMMWV, and must be air transportable inside the UH-60 Helicopter in one lift.
5. The system must include a water distribution system capable of dispensing water through one dispensing point at a minimum rate of ten Gallons Per Minute (GPM).

The LWP is a fully contained mobile water purification system. The LWP consists of the following process systems and modules:

1. Raw Water Feed System
2. Ultrafiltration Module
3. High Pressure Pump Module
4. RO Module
5. Chemical Injection/ Cleaning Module
6. NBC Post-Treatment System
7. Product Water Distribution System
8. Control Module
9. Power Source
10. Additional Equipment

The field set-up for the LWP can be found in Figure 2.

Raw Water Feed System

The raw water system consists of an electrically power 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.

UF Module

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 UF membrane cartridges. This module removes suspended solids greater than 0.1 micron in size. Operation of the module is controlled by a programmable logic controller (PLC). The PLC controls the automated backwash system as well. The module contains a collapsible filtrate tank that feeds the high-pressure plunger pump. The tank is sized to allow the high pressure pump to feed the RO Module even during the UF backwash cycle. All necessary instrumentation (temperature, differential pressure, feed pressure, backwash pressure) is contained on an instrument panel for easy monitoring by the operator.

High Pressure Pump (HP) Module

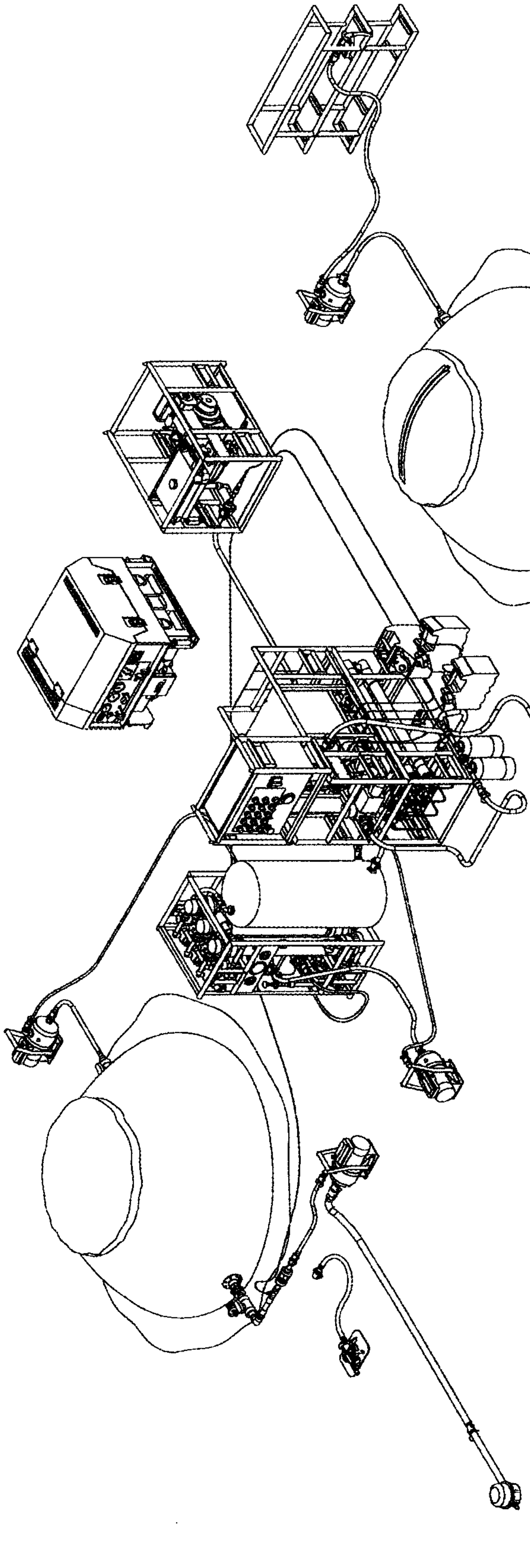
The HP module is a welded aluminum pipe frame that houses a diesel engine, a high-pressure pump and gearbox, and a 3.5-gallon diesel fuel tank. The high-pressure pump is a plunger pump that mates up to the diesel engine through a gearbox. This pump has a maximum operating pressure of 2200 pounds per square inch (psi). The pump pressurizes the feedwater prior to treatment by reverse osmosis. The module also contains a pulsation dampener to maintain flow pressure and pressure switches to protect the pump and the RO module from under and over pressurization.

Reverse Osmosis (RO) Module

The LWP employs RO to remove dissolved solids and organics from the water source. The RO Module is constructed of welded aluminum pipe frame. Seven (7) Reverse Osmosis (RO) membranes in Titanium pressure vessels are located in this frame, along with a reject control valve, pressure switch, and rupture disk. Product water piping includes sample valves for measuring the flow rate and Total Dissolved Solids (TDS) of the product water from each RO element. Elements in the titanium pressure vessels can be replaced in the field.

Chemical Injection/Cleaning Module

The chemical injection/cleaning module is a welded aluminum pipe frame that 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 the chemicals that are placed adjacent to the module. One small tank is used for either sodium bisulfite (dechlorinating agent) or coagulant depending on the source water. The second small tank is used for an antiscalant solution for the RO membranes. The third



small tank contains a hypochlorite solution for disinfecting the product water. There are three chemical injection electronic metering pumps that interface with the small chemical tanks. There is a product flow meter and totalizer meter integrated into the module piping.

NBC Post Treatment System

The NBC post treatment system is a separate component to be used when purifying NBC contaminated water. The NBC filter assembly consists of activated carbon to remove chemical warfare agents and ion exchange resin to remove radioactive contaminants. The system contains enough carbon and resin for 140 hours of operation. The system is only employed if the presence of NBC agents is suspected.

Product Water Distribution System

The product water, after chlorination and NBC post treatment (if required) is stored in a 1000 gallon collapsible fabric tank. An electric motor driven distribution pump is used to transfer water from the storage tank into 400 gallon water buffalos, 5 gallon can or canteens as required.

Control Module

The control module is a welded aluminum pipe frame that houses the electrical control panel. The panel includes selector switches, pilot lights, circuit breakers, motor starters, nine electrical receptacles for connecting the various service pumps and modules, and the Programmable Logic Controller (PLC). The PLC controls all UF module functions. The box is constructed of aluminum and is weather and High-Altitude Electromagnetic Pulse (HEMP) resistant. The control module is the connection point for all the electrical cables for the four service pumps (raw water, distribution, booster, and backwash), all LWP modules, an immersion heater, and the main power electrical power source from the 3kW TQG set.

Power Source

The 3 kW Tactical Quiet Generator (TQG) provides single phase 240 VAC power for the LWP system. All system components are power by the TQG except for the high pressure pump.

Additional Equipment

Other equipment that is associated with the LWP are Contamination Avoidance Covers (CAC) for NBC survivability enhancement and a cold weather kit. The LWP also has a hand truck and ramp to facilitate HMMWV loading/unloading and has a TRICON to transport and store all of the LWP and supporting equipment.

Water Production Technology Research and Development Program

The goal of the Water Purification Technology - Science and Technology Objective (STO) is to reduce the sustainment requirement and logistics footprint associated with water production and distribution for the Objective and Legacy Forces.

A soldier requires 1.5 to 3.5 gallons per day to prevent dehydration. When personal hygiene, combat meal preparation, and emergency medical treatment are added the planning factor becomes 4.1 gallons or 34 pounds per soldier per day. Water distribution is projected to be 30% of the Objective Force daily sustainment requirement using conventional technology.

Currently, water requirements are met by using purification assets of various sizes in the rear echelon to produce drinking water and then distributing water forward to the troops, using vehicle assets, water trailers, hoselines, and 5 gallon cans. 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. 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. In order to meet just the 3 day without resupply requirement, a brigade size element would need to have 36 900 gallon Camel water trailers and 5 2000 gallon Hippo LHS water tank racks.

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. Water resupply may transition from a daily requirement to a 3 to 5 day requirement creating a cascading reduction in the overall battlefield logistics requirements.

Water From Engine Exhaust

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.

LexCarb LLC, the contractor developing the water from exhaust prototype, has demonstrated that the water in the exhaust can be collected and purified to a level meeting military and EPA drinking water standards. A HMMWV mounted, integrated, breadboard system was able to consistently recover 50 to 60% of the water generated by the combustion process. This success has led to further work to understand the fundamental concepts and apply them to the development of an optimized system.

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.

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%. 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.

The initial prototype was constructed of commercially available components. This system fit on a HMMWV and occupied about half of the bed of a 4 seat HMMWV, with a 0.9 cubic foot heat exchanger and a 4 cubic foot demister. This system consistently recovered 50 to 60% of the theoretically available water. Test results using the original prototype led to the design of a new version that could fit entirely over the wheel arch of the HMMWV. This system had a 0.8 cubic foot heat exchanger and a 0.7 cubic foot demister.

DARPA has funded a supplemental effort to develop an advanced heat exchanger. This has led to the design and model verification of a countercurrent mesochannel heat exchanger that is even smaller, only 0.5 cubic feet, and will enable the entire system to be installed in the wheel well and thus be "invisible" to the user.

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 in the exhaust condensate included aluminum, zinc, boron, phosphorus and iron.

The initial prototype treatment train consisted of:

1. filtration
2. activated carbon fiber monolith (ACF) adsorption
3. ion exchange

The filtration step, using 2 micron glass fiber paper, 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 incorporated 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 ingenious blend of leading edge purification technologies has been required to cope with the extremely corrosive nature of the condensate and to remove toxic compounds generated through the combustion of diesel fuel.

Water From Atmospheric Humidity

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. In a hot, dry environment, this may be only 10% of the total energy requirement since a large quantity of air must first be cooled to the dew point (from approx.120 degrees F to 20 degrees F) in order to produce 1 liter of water.

Unfortunately, conventional methods of collecting this water are too large and energy intensive to be applicable to the battlefield. Commercial systems that produce water from air built using current technology and concepts are over 35 times larger and use 40 times as much energy as conventional Army water purification equipment. One example is a water generation system that produces 600 gallons per **day** of water from air which is slightly larger than the Army's 600 gallon per **hour** ROWPU. In order to have military utility, water from air systems must obviously be brought more in line with the size and energy efficiency of current water purification equipment.

Even though water is a critical resource it is a low value product, consider the cost the consumer is willing to pay for tap water, so the amount of research funding is limited. Furthermore, the goals of the bulk of the research currently being conducted are to (1) ensure water purified from traditional sources meets current and emerging drinking water standards and (2) reduce the cost of purifying traditional water sources.

Water from air is not currently an economically viable alternative to traditional water purification due to the large energy requirements and is therefore not being pursued in any significant manner. In those few instances where it is being investigated, the applications are for fixed facilities which don't have the stringent size, weight, and power limitations associated with vehicle embedded or mobile applications.

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, was the fact that the water could be removed from the carbon with less energy than required for traditional adsorbents. The team is now developing and testing a laboratory prototype. The goal with this new prototype is to try and achieve 90% relative humidity in the product air stream when starting from a 20% or less relative humidity in the source air stream. 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 to develop an adsorbent based system that enhances performance by using a more efficient and lighter weight adsorbent coupled with innovative condensation approach such as using engine waste heat to desorb the water as a high temperature stream which can then be condensed.

Other approaches supported by DARPA and TARDEC will investigate new ways to condense water based on facilitated membrane transport, graded and 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 graded and variable surface energy project, membranes are under development that will either have a graded surface energy or water affinity through a pore or can be induced to change their affinity for water. In the case of the variable surface energy materials, the hydrophobicity/ hydrophilicity can be varied using electric current. 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 current causing the water to bead up and be collectable by a method such as electroosmosis.

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 and small units, 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 reduce the 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.

Summary

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. Soon to be fielded purification systems, such as the TWPS and LWP, will provide safe drinking water to all US forces and will meet the Army Chief of Staff's goals. Future technologies being developed under the Water Purification Technology STO 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.

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